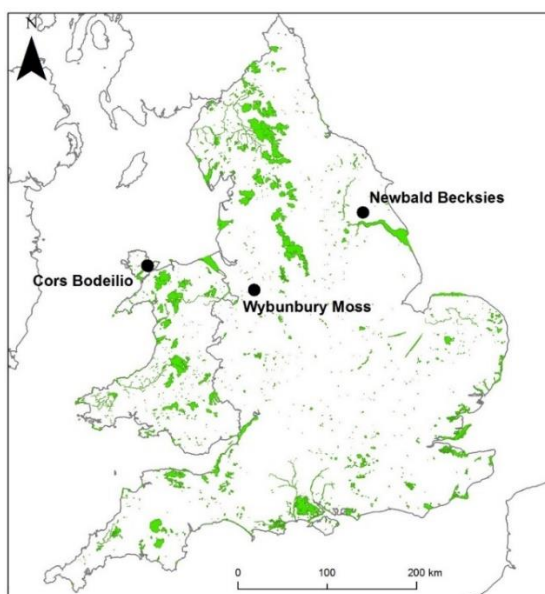




# Atmospheric deposition at groundwater dependent wetlands Phase 2- Nutrient source apportionment case studies from England and Wales

British Geological Survey

Internal Report OR/17/021





# Atmospheric deposition at groundwater dependent wetlands Phase 2- Nutrient source apportionment case studies from England and Wales

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## Keywords

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Atmospheric Deposition, Nitrate,  
Nitrogen, Water Framework  
Directive, Habitats Directive.

## Front cover

Map showing all designated  
GWDTEs in England and Wales  
(in green) with location of the  
three study sites included within  
this report.

## Bibliographical reference

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# Executive Summary

Groundwater dependent terrestrial ecosystems (GWDTEs) face multiple pressures from both atmospheric and terrestrial sources, resulting in the loss of protected habitats and biodiversity.

One of the most critical issues facing GWDTEs in England and Wales is anthropogenic pollution from nutrients. Anthropogenic nutrients can originate from a wide range of sources including industry and agriculture, and can be transmitted via multiple pathways including; surface waters, catchment runoff, groundwater, and atmospheric deposition. These multiple pathways pose a problem for environmental regulators and managers. In order to reduce nutrient damage to wetlands, environmental regulators must first have the tools to identify the dominant sources and pathways (source attribution) of nutrients.

Environmental regulators need cost effective tools to identify the most common source of nutrients in order to implement effective measures to reduce pressures. However there are a lack of source apportionment studies for GWDTEs, and no framework by which to assess multiple sources of nitrogen. This report aims to bridge that gap by considering both atmospheric and terrestrial sources of nitrogen in one study.

Three GWDTEs were studied all characterised during previous Water Framework Directive investigations; Wybunbury Moss, Newbald Becksies and Cors Bodeilio. Each site benefited from existing monitoring data and an evidenced based conceptual model, significantly reducing costs to this project. Field data collection included; inorganic chemistry of groundwater, surface water and rainfall, nitrogen and oxygen isotopes and CFC /SF<sub>6</sub> and NH<sub>3</sub> /NO<sub>2</sub> diffusion tubes deployed to quantify atmospheric dry gaseous deposition. Desk based analysis included; modeled atmospheric source apportionment from [www.APIS.ac.uk](http://www.APIS.ac.uk), catchment nutrient modelling using the 'FarmScoper' tool and calculation and comparison of nutrient fluxes against site relevant critical loads from both modeled and measured atmospheric deposition data.

We found that;

- Modelled atmospheric deposition data ([www.APIS.ac.uk](http://www.APIS.ac.uk)) was broadly comparable to our monthly on-site data collected at the three GWDTEs, but individual sites showed differing variability in ammonia concentrations compared with the national data. Modeled data provides a reliable way to quickly assess atmospheric loading at GWDTEs for national scale assessments, however site specific assessments should undertake their own measurements of ammonia concentrations.
- Detailed on site assessments of the pressure from atmospheric deposition to individual habitats are possible using National Vegetation Classification (NVC) mapping combined with Critical Load thresholds and modelled atmospheric deposition. Together these can provide a high resolution picture at site scale, provided vegetation mapping is available.
- Open access modelling tool FarmScoper (ADAS) was successfully applied, however in both examples the modelling shows that even with land use changes the reduction in terrestrial nitrate would not be significant enough to meet the proposed groundwater 'threshold' values for nitrate.

# Acknowledgments

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We are very grateful for the numerous staff from multiple organisations who worked in partnership to undertake this truly multidisciplinary project including; hydrogeologists, atmospheric scientists, site managers, ecologists, chemists, project managers and environment regulators.

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# 1. Introduction

## 1.1 INTRODUCTION AND AIMS

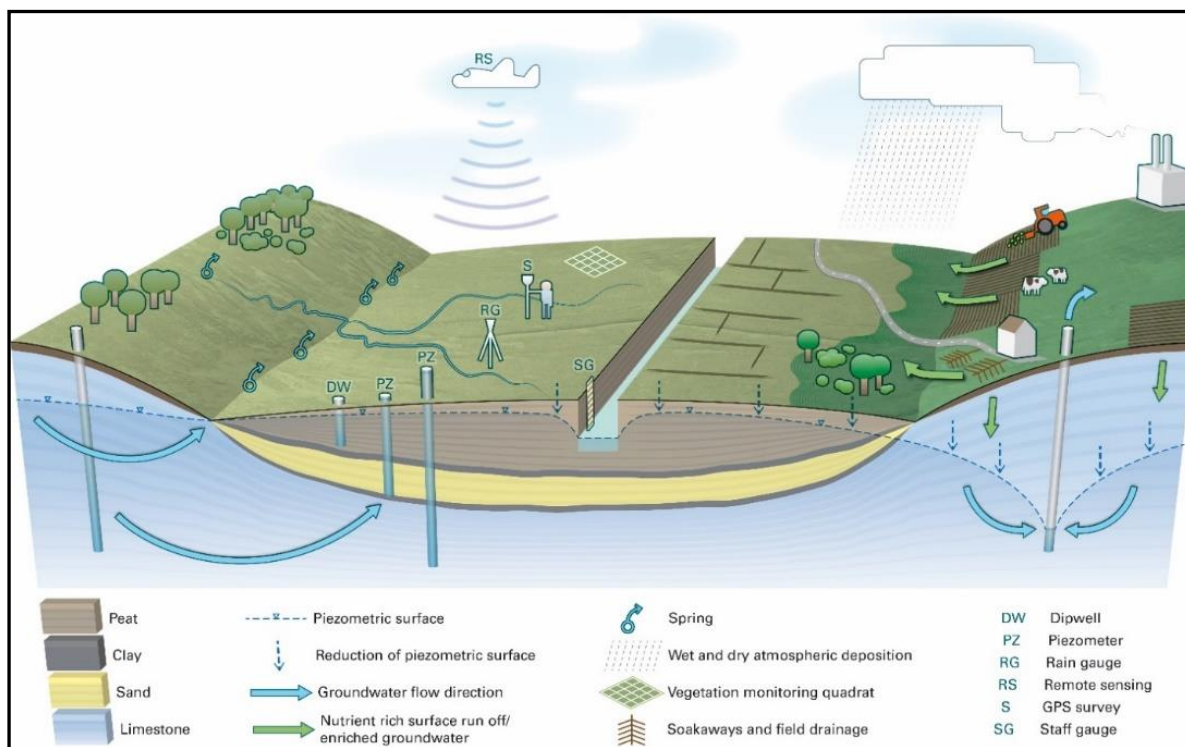
Groundwater Dependent Terrestrial Ecosystems (GWDTEs) are wetlands that critically depend on groundwater flows and/or chemistries (Schutten et al. 2011). They include both statutory sites e.g. Sites of Special Scientific Interest (SSSI), Special Areas of Conservation (SAC), National Nature Reserves (NNR) and non-statutory sites e.g. local wildlife reserves and also wetland features outside of designated series. Currently 3320 GWDTE's classified as statutory sites (e.g. SSSI, SAC, NNR) have been identified in England and Wales, however there may be many more non-statutory GWDTEs. Examples of GWDTEs include; fens, lowland bogs, flood plain meadows, petrifying springs and humid dunes.

GWDTEs can be at risk from multiple nutrient sources transmitted via various pathways (Farr & Hall, 2014). GWDTEs face multiple in-combination pressures (e.g. Figure 1-1) that could result in unfavourable ecological condition. Nutrients can be derived from both natural and anthropogenic sources and transmitted via terrestrial and atmospheric pathways. GWDTEs can themselves be both a source and sink of nitrogen (e.g. Drewer et al. 2010). Groundwater nitrogen can also be sourced from non-agricultural sources including; leaking sewers, application of sewage sludge to land, landfills and septic tanks (BGS, 1996). Some, but not all on-site management measures, such as the cutting and removal of grass can reduce nitrogen accumulating from atmospheric deposition. However, many measures only mask or limit the effects of excess nitrogen and do not actually remove it from the system (e.g. Härdtle et al. 2009; Jones et al. 2017).

Atmospheric deposition is a major pathway for nitrogen to GWDTEs, with 64 % of GWDTEs in England and Wales receiving nitrogen deposition above the critical loads for more than one habitat feature (Farr & Hall, 2014). Exceedance of critical loads is not limited to GWDTEs and is also well documented at other designated sites and habitats within the UK (Emmett et al. 2011; Stevens et al. 2010; Plantlife, 2016).

The aim of this study, which follows on from Farr & Hall (2014) is to use both novel and multidisciplinary techniques to investigate, measure and model multiple nutrient sources at GWDTEs. Atmospheric and terrestrial sources are not often considered in combination, and it is hoped that the methods described within will help regulators 'fingerprint' sources and pathways of nutrients; this is called 'source attribution'. The aim is to ensure the appropriate targeted measures are put in place to tackle the drivers of unfavourable ecological condition.

Source attribution of atmospheric deposition is provided by spatially modelled data compared against site relevant critical loads. Although principally aimed at GWDTEs the methods described within this report could also be used by environment management and catchment sensitive farming teams, for example during the delineation of, or investigations within 'drinking water protection zones'. There is also increasing discussion about the atmospheric contributions from industry and how this impacts the achievability of reduction targets that are set for many farmers.



**Figure 1-1 Common pressures and common monitoring options at GWDTEs in England and Wales**

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## 1.2 THRESHOLD VALUES (GROUNDWATER)

In England and Wales the environmental regulators, Environment Agency (EA) and Natural Resources Wales (NRW) have a duty to comply with the European Water Framework Directive, (2000/60/EEC). The WFD requires the classification of groundwater mediated chemical and quantitative pressures at GWDTEs (UKTAG, 2012a) that may result in significant damage (Whiteman et al. 2010) and unfavourable conservation status. Classification is achieved by applying a series of tests to each groundwater body, one of which is specifically designed to assess pressures from nitrate in groundwater (UKTAG, 2012a). This 'GWDTE Test' uses 'Threshold Values' (UKTAG, 2012b) for nitrate in groundwater in combination with ecological evidence to classify each GWDTE (see Appendix for full list of threshold values). When a GWDTE fails this test, by receiving groundwater that exceeds the threshold value, then the groundwater body to which it is hydrologically connected also fails. The result of this is that there are 65 (out of 305) groundwater bodies in England and Wales 'at risk' due to groundwater mediated nutrient pressures at GWDTEs (Farr & Hall, 2014). This classification is supported by the Habitats Directive (92/43/EEC) which also requires member states to maintain or restore Annex 1 habitats to favourable conservation status. In situations where groundwater is considered a possible pathway for nutrients -resulting in unfavourable condition for the GWDTE, then the environmental regulator must undertake a programme of measures to identify and reduce the pressure/s with the aim of returning the GWDTE to favourable condition.

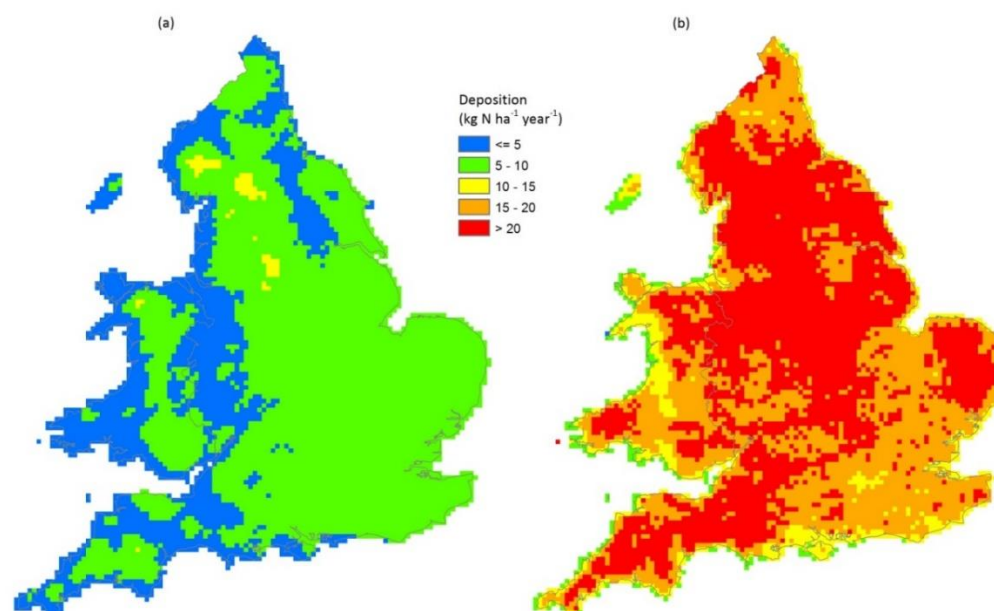


### 1.3 CRITICAL LOADS (ATMOSPHERIC)

Atmospheric deposition of nitrogen is a contributor to the decline seen in species richness in many habitats (e.g. Maskell et al. 2010). To assess the impact of atmospheric deposition ‘Critical loads’ have been developed as a policy tool to define potential impact of atmospheric deposition on multiple environmental receptors (biodiversity, plant growth, ecological processes and biogeochemical cycling of nutrients). Critical loads can provide a quantitative estimate of exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge (Nilsson & Grennfelt, 1988). Critical loads for atmospheric nitrogen deposition have been defined in Europe for a wide range of habitat types (e.g. Bobbink & Hettelingh, 2011) and are presented as a range (e.g. wet heath 10-20 kg N ha<sup>-1</sup> year<sup>-1</sup>) to encompass the variability in response of habitats to nitrogen. In the UK, for mapping purposes, a single value within each range has been applied to nitrogen-sensitive habitats (Hall et al. 2015) which enables national habitat-specific critical load maps to be compared with the national atmospheric deposition maps. This shows that 62 % of the total UK area of these habitats (including GWDTE) exceed their critical loads<sup>1</sup>. However, site-based assessments may use the lower end of the critical load range, or take account of the whole range.

### 1.4 FIRST COMPARISON OF THRESHOLD VALUES AND CRITICAL LOADS

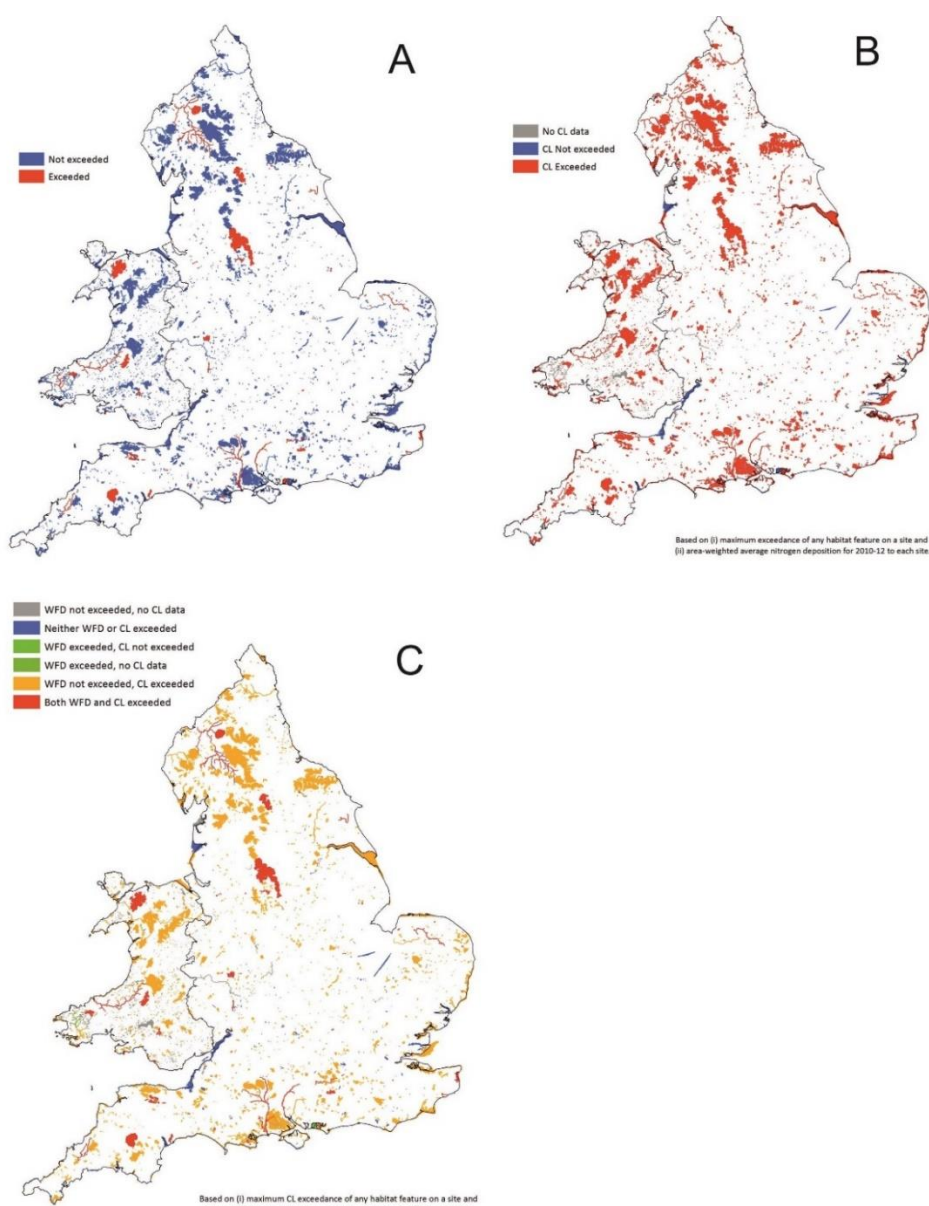
Farr & Hall (2014) considered both atmospheric and terrestrial nitrate sources in relation to the condition of groundwater dependent terrestrial ecosystems (GWDTE) in England and Wales. They spatially analysed nutrient pressures on a national scale, by combining groundwater nitrate threshold values (TV) (UKTAG, 2012b), wetland habitat condition and atmospheric nitrogen critical loads (CLempN) incorporating all of the 3320 GWDTEs in England and Wales. Unfortunately critical loads could not be assigned to 965 of the 3320 GWDTEs due to lack of habitat information on some of the smaller sites. However, the national 5 x 5 km atmospheric nitrogen deposition (Figure 1-2 a&b), derived using the ‘Concentration Based Estimated Deposition’ methodology (RoTAP, 2012), was shown to exceed the CLempN for at least one habitat feature in 90 % of the remaining 2355 GWDTE.



**Figure 1-2 Spatial coverage of CBED (Concentration Based Estimated Deposition 5x5 km nitrogen deposition to moorland for 2010-12: (a) oxidized nitrogen; (b) total (oxidized + reduced) nitrogen. Contains Ordnance Survey data licence number [100021290 EUL] © Crown Copyright and database rights 2019**

<sup>1</sup> (<http://www.cldm.ceh.ac.uk/exceedances/trends>)

Unlike atmospheric nitrogen deposition, groundwater nitrate concentrations are not available across England and Wales at a comparable scale, thus a different approach was taken to assess how many GWDTEs exceeded their groundwater nitrate Threshold Values (Figure 1-3A). This approach relied on having direct evidence of measured nitrate concentrations, either within the GWDTE or within the adjacent groundwater body collected from Water Framework Directive (WFD) monitoring programmes. This data was analysed by the regulatory bodies via several ‘tests’ one of which assesses the risk to any given GWDTE from nitrate concentrations within a hydrologically connected groundwater body (UKTAG, 2012). The WFD test resulted in 6 groundwater bodies being assigned a Poor Status (that is a failure for the WFD) and a further 65 WFD groundwater bodies classed as ‘at risk’ of poor status. GWDTEs that exceeded their Threshold Value (Figure 1-3A) were combined with GWDTEs that exceed their critical load (Figure 1-3B) to produce a single map showing GWDTEs that exceed both their Threshold Value and Critical Load (Figure 1-3C). This was the first time these assessments have been combined into one map and allowed GWDTEs that were at risk of pressure from multiple sources and pathways to be identified.

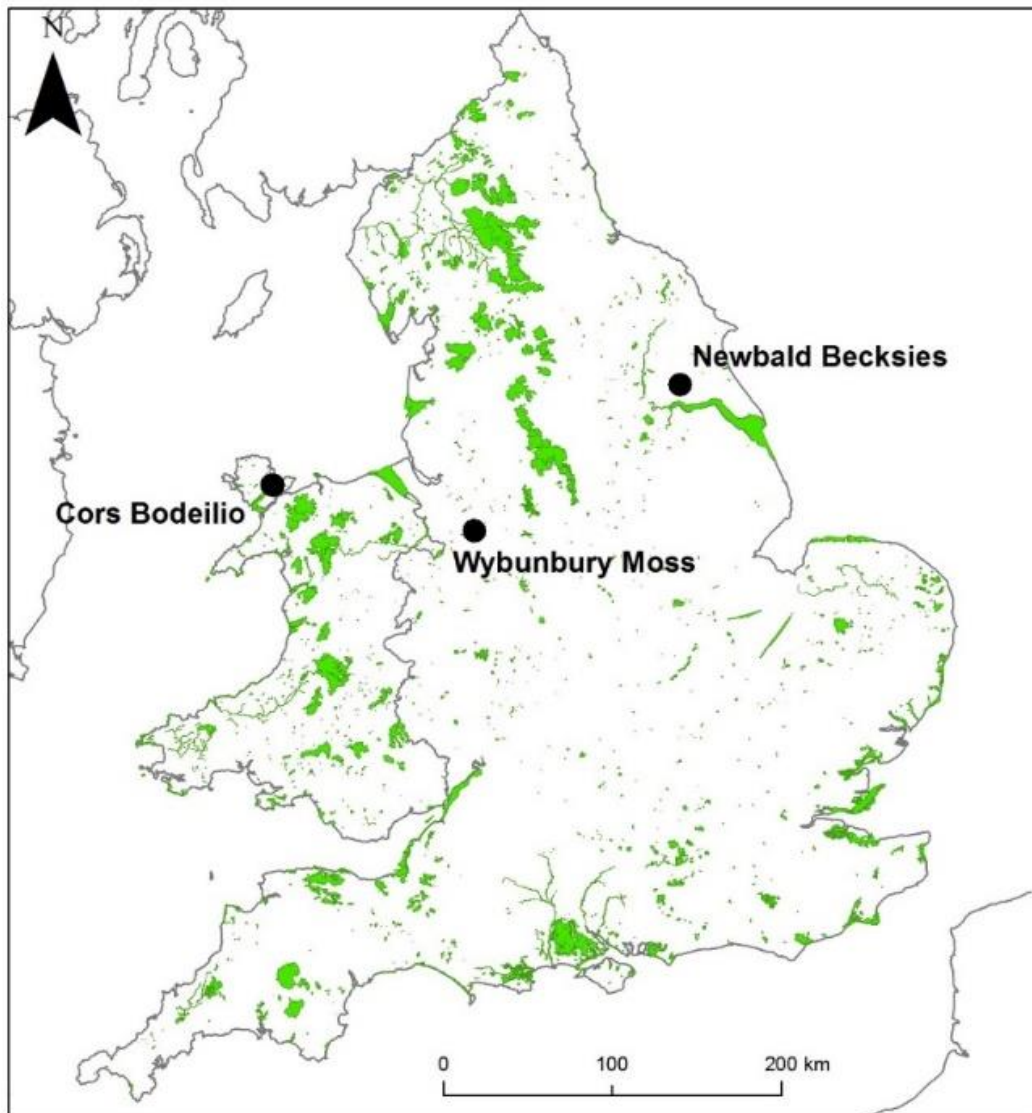


**Figure 1-3 Location of GWDTEs that exceed their Water Framework Directive ground water ‘threshold value’ (A), atmospheric critical load (B) and then in combination where both threshold values and critical loads are exceeded (C) (Farr & Hall., 2014). Contains Ordnance Survey data licence number [100021290 EUL]**

## 2. Methodology

### 2.1 SITE SELECTION

Farr & Hall (2014) considered which of the GWDTE in England and Wales were most suitable for source apportionment study, producing a list of potential study sites for this phase of the work. In order to be able to undertake a source apportionment study it was agreed that each of the wetlands should exceed both their relative WFD nitrate threshold value (see UKTAG, 2012) and their associated Critical Load. In addition each wetland should be identified as a ‘groundwater dependent terrestrial ecosystem’ or ‘GWDTE’ (UKTAG, 2004); must have been the subject of a previous ecological and hydrogeological investigation, including a robust conceptual model, defined groundwater and surface water catchment and pre-existing monitoring network and historical data (Table 1). Only wetlands where site managers or EA/NRW/NE staff that are able and willing to assist with data collection were selected. Finally, the remaining sites were discussed with the project team and expert judgment was used to agree upon the final study sites. The sites chosen were **Wybunbury Moss, Cheshire; Newbald Becksies, Yorkshire and Cors Bodeilio, Anglesey** (Figure 2-1).



**Figure 2-1 Location of Wybunbury Moss, Newbald Becksies and Cors Bodeilio. The green areas represent the 3320 designated wetlands that are classified as ‘groundwater dependent terrestrial ecosystems’ (GWDTE). Contains Ordnance Survey data licence number [100021290 EUL] © Crown Copyright and database rights 2019.**

Examples of recent ecological and hydrological work on the study sites include, but are not limited to:

- **Wybunbury Moss** (Ingram & Seymour, 2003; Moore, 2009; Terradat Ltd, 2009; Environment Agency, 2011; Wheeler et al. 2015, Eades et al. 2015 & Tratt et al. 2015, Callaghan, 2015, Bellamy, 2015 & Environment Agency 2017a),
- **Newbald Becksies** (Chiverrell, 2004; Terradat Ltd, 2009; Yorkshire Water Services, 2006; 2007; Environment Agency, 2008; 2011; Wilkinson, 2009 and Environment Agency 2017b) and
- **Cors Bodeilio**, Anglesey (e.g. Schlumberger Water Services, 2010; Natural Resources Wales, 2015; Jones, 2018).

**Table 1 Summary of site selection criteria**

<b>Criteria</b>	<b>Wybunbury Moss</b>	<b>Newbald Becksies</b>	<b>Cors Bodeilio</b>
>Critical Load	Yes	Yes	Yes
>WFD nitrate threshold value	Yes	Yes	Yes
Groundwater Dependent Terrestrial Ecosystem	Yes	Yes	Yes
Hydrogeological conceptual model	Yes	Yes	Yes
Chemical and water level data	Yes	Yes	Yes
Groundwater & Surface water catchments delineated	Yes	Yes	Yes
Existing monitoring network	Yes	Yes	Yes
Availability of NVC data	Yes	Yes	Yes
Site managers and local EA/NE/NRW staff to assist with investigation	Yes	Yes	Yes
Agreed by the steering committee	Yes	Yes	Yes

## **2.2 DELINEATION OF GROUNDWATER AND SURFACE WATER CATCHMENTS**

To minimise project costs only sites with pre-defined groundwater and surface water catchments were selected. The following provide details about how the groundwater and surface water catchments were delineated.

**Groundwater catchments** have been delineated as part of previous Water Framework Directive investigations. Methodologies for the delineation and description of groundwater catchments are described in the following reports; Wybunbury Moss (Ingram & Seymour, 2003; Moore, 2009; Environment Agency, 2011; Wheeler et al. 2015); Newbald Becksies (Environment Agency, 2008; 2011; Terradat Ltd, 2009; Wilkinson, 2009) and Cors Bodeilio (Schlumberger Water Services, 2010; Natural Resources Wales, 2015).

**Surface water catchments** were delineated for all the GWDTEs in England and Wales. Using a GIS system the GWDTE polygons and the 10 m DTM (Digital Terrain Model) were uploaded. Using the ‘catchment tool’ (ArcView ‘HydroTools’) surface water catchments / topographical watershed were generated for each GWDTE.

## 2.3 SAMPLE LOCATIONS

Each of the three GWDTEs have pre-existing monitoring networks, installed for Water Framework Directive targeted investigations. Site visits were undertaken by site managers, area EA or NRW staff and Gareth Farr (BGS) to decide on the most representative samples locations for this study. Monitoring locations were selected to represent a range of pathways (groundwater, surface water, precipitation) to each GWDTE. Sample point locations, type, sampling frequency and the associated ‘WIMS’ number are summarised in Table 2. ‘WIMS’ is the water quality database on which all geochemical information is stored at the Environment Agency (EA) and until recently at Natural Resources Wales (NRW). Inorganic water chemistry data from this study can be retrieved from ‘WIMS’ by request to either the EA or NRW and is also included within the Appendix to this report.

**Table 2 Sample Location and Programme**

Site	Name	Type 1	Type 2	Inorganic Water Chemistry	Isotopes	CFC - SF6	Fluorecence	Diffusion tubes	Data Type	Frequency	WIMS	E	N
Newbold Beckies	Spring_1	Groundwater	Spring	Yes	Yes	Yes	Yes	No	Chemistry	Biannual	400G0100	491900	437109
	Spring_West	Groundwater	Spring	Yes	Yes	Yes	No	No	Chemistry	Biannual	400G0114	491710	437094
	Outflow 'StarFlow'	Surface water	Flow meter	No	No	No	No	No	Discharge	Biannual	n/a	491599	437069
	Borehole_West	Groundwater	Borehole	Yes	Yes	No	Yes	No	Chemistry/ level	Biannual	400G0099	491720	437059
	Borehole_Central	Groundwater	Borehole	Yes	Yes	No	Yes	No	Chemistry/ level	Biannual	400G0097	491789	437075
	Borehole_East	Groundwater	Borehole	Yes	Yes	Yes	Yes	No	Chemistry/ level	Biannual	400G0098	491882	437097
	Pipe	Groundwater	Old pipe	Yes	Yes	No	Yes	No	Chemistry	Biannual	49105159	491655	437082
	Diffusion_Tubes	Atmospheric		No	No	No	No	Yes	Deposition	Monthly	400G0113	491877	437123
Wybunbury Moss	Rainfall	Rainfall	Rain gauge		No	No	No	No	Rainfall	Monthly	400G0113	491877	437123
	Borehole_SGA3	Groundwater	Borehole	Yes	Yes	Yes	Yes	No	Chemistry/ level	Biannual	88022451	369594	350383
	Borehole_D	Groundwater	Borehole	Yes	Yes	No	No	No	Chemistry/ level	Biannual	88022302	369589	350384
	Piezo_PTB2	Groundwater	Piezometer	Yes	Yes	Yes	No	No	Chemistry/ level	Biannual	88022443	369637	350260
	Piezo_PTC	Groundwater	Piezometer	Yes	Yes	Yes	Yes	No	Chemistry/ level	Biannual	88022445	369642	350233
	Main_Pool	Surface water	Surface pool	Yes	Yes	No	Yes	No	Chemistry	Biannual	88023759	369574	350213
	Pool_1	Surface water	Surface pool	Yes	Yes	No	Yes	No	Chemistry	Biannual	88023758	369734	350128
	Outflow_weir	Surface water	Outflow	Yes	Yes	No	Yes	No	Chemistry	Biannual	88023757	369972	350107
	Lag_Fen	Groundwater	Lag Fen	Yes	Yes	No	Yes	No	Chemistry	Biannual	88023760	369606	350367
	Diffusion_Tubes	Atmospheric		No	No	No	No	Yes	Deposition	Monthly	88023761	369649	350240
Cors Bodeilo	Rainfall	Rainfall	Rain gauge	Yes	No	No	No	No	Rainfall	Monthly	88023761	369649	350240
	Axial_Drain	Surface water	Outflow	Yes	Yes	No	Yes	No	Chemistry	Biannual	28392	250227	377584
	Fly_Orchid_Spring	Groundwater	Spring	Yes	Yes	Yes	Yes	No	Chemistry/ discharge	Biannual	28113	250020	377720
	Dipwell_16	Groundwater	Dipwell	Yes	Yes	No	No	No	Chemistry/ level	Biannual	n/a	250531	377189
	Piezo_BD2a	Groundwater	Piezometer	Yes	Yes	Yes	Yes	No	Chemistry/ level	Biannual	28249	250346	377539
	Bodeilo_Farm_Spring	Groundwater	Spring	Yes	Yes	Yes	Yes	No	Chemistry	Biannual	28108	249722	377703
	Drain nr Car Park	Groundwater	Drain	Yes	Yes	No	No	No	Chemistry	Biannual	n/a	250645	377316
	Treatment_Wetland	Groundwater	Drain	Yes	Yes	No	Yes	No	Chemistry	Biannual	n/a	250631	377434
	Diffusion_Tubes	Atmospheric		No	No	No	No	Yes	Deposition	Monthly	n/a	250531	377342
	Rainfall	Rainfall	Rain gauge	Yes	No	No	No	No	Rainfall	Monthly	40000506	250531	377342

## 2.4 INORGANIC WATER CHEMISTRY

Water chemistry data allows waters to be attributed to different sources, nutrient concentrations to be measured and trends to be identified. Water chemistry data can also be used to improve site conceptual understanding. Field measurements for pH, temperature, electrical conductivity and dissolved oxygen were measured at each sample point using a ‘YSI Pro’ field meter. A ‘SevernGo’ pH, EC and temperature meter used as backup. Field meters were calibrated daily for pH and EC using a two-point calibration (pH 4 – 7 and EC 716 – 1413  $\mu\text{S}/\text{cm}$ ). Samples were collected from a range of locations at each wetland, including boreholes, piezometers, springs, surface waters, pools, rainfall gauges and drainage pipes. Samples from springs were obtained from flowing water from as close to the source as possible. Bog surface pools (e.g. Wybunbury Moss) were sampled from their edges and only where access was possible. Boreholes and piezometers were sampled

using a 'WaSP-P3' submersible 12V pump, capable of purging sufficient volumes of water whilst also being light enough to transport across uneven terrain. Water samples were collected only when the field parameters (pH, EC, Temperature, Dissolved Oxygen) had stabilised. Two bottles of unfiltered water (1 litre and 125 ml) and one filtered using a 0.45  $\mu\text{m}$  filter attached to a 50 ml syringe (125 ml) were collected. The samples were returned the same day to a fridge at either Environment Agency or Natural Resources Wales offices, from where they were collected by courier and delivered to the laboratory.

Water analysis was undertaken at both Environment Agency and Natural Resources Wales Laboratories, both of which are UKAS accredited. Apart from nitrate, only water chemistry data from the period 2015-2016 have been included within the report, it should be noted that water chemistry datasets, although intermittent, cover the time periods of (Wybunbury 2001-2015, Newbald Becksies 2009-2016 and Cors Bodeilio 2007-2016). The full water chemistry data can be requested from the relevant organisation by referencing the 'WIMS' sample point code attributed to each location (Table 2).

## 2.5 OXYGEN AND NITROGEN ISOTOPES

Oxygen and nitrogen isotopes can be used in conjunction with a conceptual model and groundwater chemistry data to better understand the source of nitrate in a water sample. Isotope samples were collected twice during the study to look at seasonal changes, during March 2016 (spring) and August 2016 (summer). The samples were collected at the same time as the inorganic water chemistry (see above) however they were filtered through 0.2  $\mu\text{m}$  filters, into 50 ml sterile polypropylene centrifuge tubes.

The samples were then frozen and delivered to Dr Sarah Wexler (University East Anglia) for analysis. The following text supplied by Dr Wexler explains the methodology for analysis; 'Samples were prepared using a method developed by Sigman et al. (2001) and Casciotti et al. (2002) known as the denitrifier method. This uses a bacterial strain that converts nitrate and nitrite in an aqueous sample to nitrous oxide gas, for isotopic measurement on a GCIRMS. The nitrous oxide in the sample vial is purged from the vial with helium using a double needle, passed through a Nafion drier to remove water, through a sodium hydroxide and magnesium perchlorate scrubber to remove  $\text{CO}_2$  and more water, a dry ice/ethanol trap ( $-78^\circ\text{C}$ ) as a final drying step, and a trap to remove volatile organic compounds (VOCs). The sample is pre-concentrated using liquid nitrogen, passed through a gas chromatograph with a Poraplot Q column to separate out any remaining  $\text{CO}_2$  and VOCs and analysed on a GEO 20-20 isotope ratio mass spectrometer at  $m/z$  44, 45 and 46, from which ratios  $\delta^{15}\text{N}$  and  $\delta^{18}\text{O}$  values are calculated. For  $\delta^{17}\text{O}$  analysis, the nitrous oxide is passed through a gold furnace held at  $850^\circ\text{C}$  to thermally decompose the gas into molecular nitrogen and oxygen, and analysed at  $m/z$  32, 33 and 34 from which  $\delta^{17}\text{O}$  and  $\delta^{18}\text{O}$  and  $^{17}\text{O}$  excess,  $\delta(^{17}\text{O})$  are calculated. Samples are calibrated using the nitrate isotope reference materials IAEA-NO-3, USGS 34 and USGS 35, which are prepared and analysed alongside samples in each batch, and quality is controlled using an in house reference (a freshwater nitrate-containing sample). Final results are reported with respect to international reference materials Air- $\text{N}_2$  and VSMOW (Vienna Standard Mean Ocean Water)'.



## 2.6 CFC AND SF<sub>6</sub> AGE DATING

Chlorofluorocarbons (CFCs) and sulphur hexafluoride (SF<sub>6</sub>) can be used to age date groundwater (e.g. Gooddy et al. 2006). Since the production of CFCs & SF<sub>6</sub> ended they have remained in the environment but at known concentrations allowing them to be used as tracers to provide ages for recharge to groundwater. Samples were collected from three sample points at each wetland (Table 2). The rationale behind the selection of sample points was to target areas where groundwater is known to discharge into the site (e.g. via springs or seepage areas) or in boreholes that were directly up hydrological gradient from the wetland. It is useful to know the age of water in these areas as it may also be used to infer the age of the nitrate or to consider the potential travel time to the wetland. The samples were collected during March 2016, at the same time as both field parameters, inorganic water chemistry and N & O isotope samples, described above. The field method requires the collection of unfiltered water samples without atmospheric contact, in glass bottles contained within metal cans, applying the displacement method of Oster et al. (1996). This method rules out sampling surface waters and requires purging of boreholes and springheads (using the 12V WaSP™ submersible) to ensure water entering the glass jar has had no atmospheric contact. The samples were analysed by Dr Daren Gooddy (British Geological Survey).

## 2.7 FLUORESCENCE

Fluorescence can be used to understand the source and composition of dissolved organic matter in groundwater (e.g. Lapworth et al. 2009). Samples were collected from each site during March 2016, at the same time and using the same methodology as both the inorganic and N and O isotopes samples described above. Samples were analysed by Fluorescence Excitation-Emission Spectroscopy on a Varian Cary Eclipse Spectrometer at BGS Wallingford following methods outlined in Lapworth et al. (2009). The samples were analysed by Dr Dan Lapworth (British Geological Survey). Samples can be processed by BGS in batches of 30 minimum at approximately £360 (prices correct as of 2017) although detailed interpretation can incur additional costs.

## 2.8 PRECIPITATION

To reduce project costs, precipitation data was collated from existing weather stations near to the three study locations. The weather stations / references used are:

- **Wybunbury Moss:** Daily total from ‘Worleston Sewage Treatment Works’, Station Number 553564, Easting 366464, Northing 357446
- **Newbald Becksies:** Daily total from tipping bucket Station Number NE083 Easting 492160 Northing 437203, ~ 0.2 km north-east of Newbald Becksies (Environment Agency)
- **Cors Bodeilio:** Daily total precipitation from Llyn Cefni rainfall station, Easting 244490 Northing 377120, ~4.5 km west of Cors Bodeilio (Natural Resources Wales)

## 2.9 SCHEMATIC CONCEPTUAL MODELS

Schematic conceptual models are used to illustrate the location of the monitoring points discussed in this report in relation to the wider hydrological context of each site. To reduce project costs the conceptual models were based on pre-existing studies (e.g. Ingram & Seymour, 2003; Environment Agency, 2011a; Environment Agency, 2011b; Wilkinson, D. 2009; Terradat, 2009; Schlumberger Water Services, 2010). The reader should be aware that these conceptual models are not drawn to scale. Conceptual models should be revisited and improved in an iterative process as better evidence is collected. For a useful guide to developing and refining your own ‘Eco-hydrogeological’ conceptual model see Low et al. (2016).

## 2.10 AIR POLLUTION INFORMATION SYSTEM (APIS) AND SITE RELEVANT CRITICAL LOADS

The Air Pollution Information System (APIS) <http://www.apis.ac.uk> provides a portal for users to look up pollutant values for habitats by location or by designated site (SAC, SPA, A/SSSI), and where available, critical loads and critical levels and their exceedances. The website includes easy to follow menus and guides.

The pollutant data available are:

- Acid deposition (sum of non-marine sulphur and total nitrogen deposition)
- Nitrogen deposition (total: sum of oxidised plus reduced nitrogen deposition)
- Ammonia concentrations (NH<sub>3</sub>)
- Nitrogen oxide concentrations (NO<sub>x</sub>)
- Sulphur dioxide concentrations (SO<sub>2</sub>)
- Ozone concentrations (O<sub>3</sub>)

The acid and nitrogen deposition data are the 5x5 km resolution “Concentration Based Estimated Deposition” (CBED) 3-year average deposition data; the UK CBED data sets are in the process of being made publicly available via EIDC (<http://eidc.ceh.ac.uk/>) and UK-AIR (<https://uk-air.defra.gov.uk/>).

The concentrations of NH<sub>3</sub>, NO<sub>x</sub> and SO<sub>2</sub> on APIS are also 5x5 km data averaged over three years; the ozone data are 1x1 km data averaged over five years. Further information on the pollutant data is provided in pop-up boxes when using APIS.

APIS provides a list of the available nitrogen critical loads for different habitats (<http://www.apis.ac.uk/indicative-critical-load-values>) and in the online searches applies the corresponding critical load for the habitat in question; where a critical load does not exist for a particular habitat, if appropriate, a critical load for a similar habitat may be applied. Acidity critical loads are based on the dominant soil type within each 1x1 km grid square together with ecosystem-specific parameters; they have only been calculated for a limited number of habitat types and do not include wetlands, with the exception of bogs where the critical loads are based on peat soils.

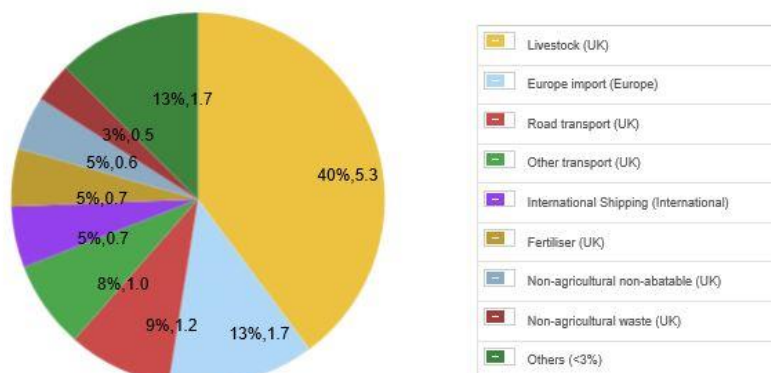
For designated sites, “Site Relevant Critical Loads” (SRCL) are used; these utilise the same critical loads as outlined above, but the critical loads that have been assigned to the interest features sensitive to acidity and/or nutrient nitrogen within each site.

The SRCL section of APIS also includes information on emission sources, and source attribution for nitrogen deposition to each site; it is based on data from the FRAME national-scale atmospheric dispersion model and provides a breakdown by local and long-range sources (Figure 2-2). It does not have any information on the amount of nitrogen entering a site via groundwater.



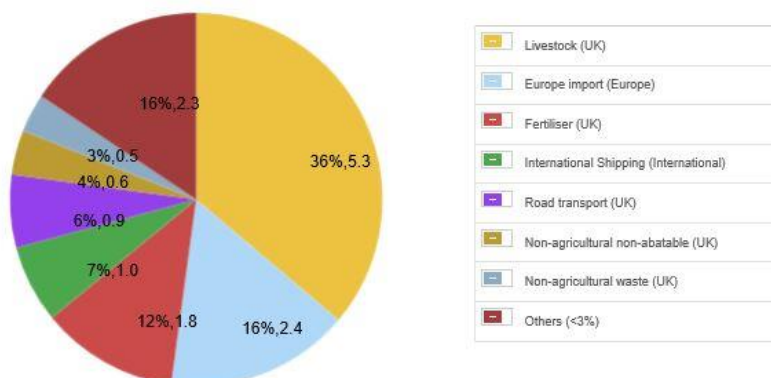
## Wybunbury Moss

— Pie Chart: Sources ranked by total Nitrogen deposition (Kg N/ha/yr)



## Newbald Becksies

— Pie Chart: Sources ranked by total Nitrogen deposition (Kg N/ha/yr)



## Cors Bodeilio

— Pie Chart: Sources ranked by total Nitrogen deposition (Kg N/ha/yr)

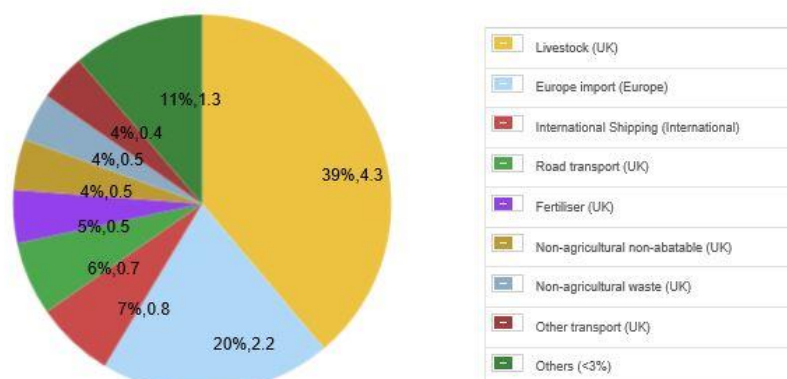


Figure 2-2 APIS Pie charts source ranked by total Nitrogen deposition (Kg N/ha/yr)

## 2.11 ATMOSPHERIC DEPOSITION MONITORING AND DEPOSITION VELOCITY

On site deposition data was measured in order to compare to the modelled APIS data described in Chapter 2.10. This was done to assess the robustness of using the modelled APIS data in future studies and to better understand the seasonal variation in deposition. Figure 2-3 shows the atmospheric deposition monitoring station at Newbald Becksies, the same design was installed at Wybunbury Moss and Cors Bodeilio. Open areas near the centre of each site were selected and for sites that had large grazing animals the diffusion tubes were placed inside small fenced off compounds to prevent grazing animals from using them as a back scratcher. An additional sample location was installed at Newbald Becksies located on top of the hill near the site to compare deposition directly at the site and on the top of the hill. The top of the holder measures 1.8 m above ground level. Plastic bird deterrent spikes were attached to the top to prevent birds using the station as a perch.

NH<sub>3</sub> and NO<sub>x</sub> Diffusion tubes (Enviro Technology Services [www.et.co.uk](http://www.et.co.uk)) are shown attached to the upper cross bar and the NH<sub>3</sub> ALPHA badge sampler, provided by Centre for Ecology and Hydrology, is placed underneath an upturned plant pot saucer to protect it from rain. NO<sub>x</sub> and NH<sub>3</sub> diffusion tubes were exposed in triplicate, with an additional tube not exposed and used as a field-blank to account for potential contamination during transport and storage. Diffusion tubes deployed for a total period of 12 months, with new tubes being installed on a monthly basis.

The CEH ALPHA badge samplers were installed for two sampling periods (~ two months) in parallel with the Enviro Tech diffusion tubes as NH<sub>3</sub> diffusion tubes are known to have a less sensitive limit of detection, and tend to over-sample compared to active denuder sampling using continuous monitoring. While the ALPHA samplers are also a passive sampling method, in cross-comparison studies, they tend to perform better than diffusion tubes, giving values closer to those reported from active sampling methods.

A UK average deposition velocity was calculated from outputs from the EMEP4UK atmospheric chemistry transport model run by CEH Edinburgh for each of the broad vegetation types: woodland, moorland and grassland. In reality deposition velocities are highly dynamic, governed by feedbacks with pollutant concentrations, and interactions with meteorology and other pollutants. The EMEP4UK outputs provide a UK-spatial and temporally average deposition velocity for each pollutant, which is a ‘realised deposition velocity’ and takes into account all the factors above. Ideally, a separate deposition velocity would be derived for each vegetation type at each site, based on wind velocity, ammonia concentrations and information on vegetation height, but this was beyond the practical scope of the project. Therefore, in this project, the UK average deposition velocity for the relevant vegetation type (in this case moorland/grassland – See Appendices) was applied for all the monitoring sites.

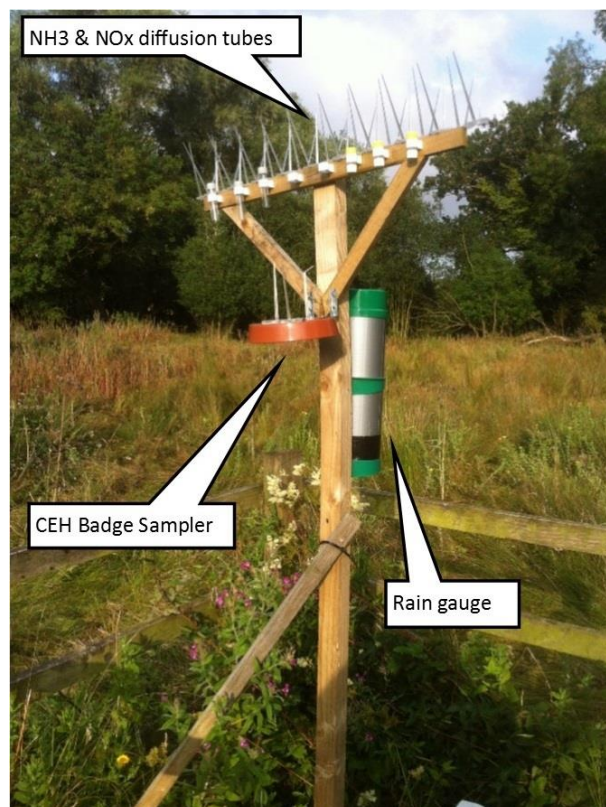


Figure 2-3 Atmospheric deposition monitoring station

## 2.12 ATMOSPHERIC NITROGEN BUDGET

Gaseous concentrations of  $\text{NO}_x$  and  $\text{NH}_3$  were converted to dry deposition fluxes using deposition velocities from the EMEP4UK model of  $1.13 \text{ mm s}^{-1}$  and  $6.44 \text{ mm s}^{-1}$  respectively, for moorland/grassland vegetation. It was assumed that the majority of site vegetation falls into this category rather than woodland or crops which have different deposition velocities. The values were converted to fluxes for each period of exposure, then summed to give a total for the exposure period. Where this period did not equate to a calendar year due to missed samples (e.g. Cors Bodeilio), this was scaled to a calendar year based on the number of exposure days.

Rainfall chemistry for oxidised (total oxidised N) and reduced (ammonia-N) nitrogen was converted to wet N fluxes by multiplying by accumulated daily rainfall over the rainfall sample collection period. Rainfall volumes from the nearest Met-office approved collection site were used, as follows: Cors Bodeilio (RAF Valley), Wybunbury Moss (Wood), Newbald Becksies (North Cave). In the case of Cors Bodeilio, RAF Valley was used as the reference rather than Llyn Cefni as the latter appeared to over-estimate rainfall by over 50 %.

For both dry gaseous N and wet deposited N, we used a calendar year of 1 Dec 2015 to 30 Nov 2016 for scaling. We ignored data outside of this period, since both  $\text{NO}_x$  and  $\text{NH}_3$  show a distinct seasonal pattern and inclusion of adjacent sampling values would skew the annual calculation. Dry and wet fluxes were combined to give an annual deposition of N.

## 2.13 NITROGEN DEPOSITION LOADS AND FLUX VIA SURFACE WATER & GROUNDWATER CATCHMENTS

Surface water catchments are delineated for all GWDTEs in England and Wales, so an approach to apply pre-existing modelled nitrogen deposition data could be a useful approach for desk based assessment of loading at GWDTEs.

Surface water and groundwater catchments were delineated for each GWDTE as described in Chapter 2.2 and are illustrated for each site in Figures 3-1, 3-2, 3-5.

Digital boundaries and a list of designated feature habitats for each of the three study sites were taken from the UK “Site Relevant Critical Loads” (SRCL) database (used by CEH for UK-wide critical loads work for Defra: <http://www.cldm.ceh.ac.uk/critical-loads/site-specific>). Nutrient nitrogen critical loads have been developed under the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) (Bobbink & Hettelingh, 2011) and assigned to habitat classes of the European Nature Information System (EUNIS: Davies & Moss, 2002). The SRCL database includes linkage tables that relate the designated feature habitats to the closest EUNIS habitat class and corresponding critical loads (Hall et al. 2015). The individual critical load values applied to each habitat feature are those recommended and used by the Statutory Nature Conservation Bodies (SNCBs) in casework and for Article 17 reporting for the EU Habitats Directive (<http://www.apis.ac.uk/indicative-critical-load-values>).

Total atmospheric nitrogen deposition (i.e. oxidised plus reduced) for 2011-13 Concentration Based Estimated Deposition (CBED) <http://www.pollutantdeposition.ceh.ac.uk/data> were used to calculate the total nitrogen deposition load (input) to each catchment area, as well as the nitrogen deposition flux. The CBED data are mapped on a 5×5 km grid for the UK and separate values are available for deposition to “moorland” (i.e. low growing vegetation) and to woodland; “grid-average” values are also available that average the deposition for all land use types in a grid square. The CEH Land Cover Map 2007 (LCM2007: <http://www.ceh.ac.uk/services/land-cover-map-2007>), at 25 m resolution, was used to identify the area and spatial coverage of woodland and non-woodland land cover within each catchment, so that area-weighted deposition loads and fluxes could be calculated using the appropriate ecosystem deposition data.

## **2.14 ATMOSPHERIC NITROGEN DEPOSITION EXCEEDANCES OF SITE RELEVANT CRITICAL LOADS**

The Site Relevant Critical Loads (SRCL) database lists the designated feature habitats in SSSIs, SACs and SPAs and their associated SRCL values. However there is no UK-wide digital spatial dataset identifying the location and area of the feature habitats within each site; therefore, for the purposes of this analysis, we assumed that each feature habitat can occur across the entire GWDTE. Exceedances (i.e. the excess deposition above the critical load) of the SRCL for each feature habitat within each of the three study sites, were calculated using CBED deposition to “moorland” (i.e. low growing vegetation) since all designated features are grasses/mires/fens/bogs.

## **2.15 ATMOSPHERIC NITROGEN DEPOSITION CRITICAL LOAD EXCEEDANCES USING NVC MAPS**

It is possible to produce a more detailed map showing exceedances of nitrogen at an individual habitat scale. This can be achieved where digital spatial habitat maps are available. We used Cors Bodeilio as an example where detailed National Vegetation Classification (NVC) maps have been produced (Rodwell, 1991,1992, 1995, 2000; Jones, 2018). Firstly, as nitrogen critical loads are assigned to EUNIS habitat classes (not individual NVC communities) it was necessary to translate the NVC maps into EUNIS habitats. This was done by using the look up tables on the JNCC website ([jncc.defra.gov.uk/page-1425](http://jncc.defra.gov.uk/page-1425)) and linking the NVC to the EUNIS habitat. Although there is not a simple one-to-one relationship between the two sets of codes as one EUNIS habitat may contain several NVC communities. Then, if a critical load existed for the matching EUNIS code, this was applied to the polygon feature of the spatial habitat map. If there was no critical load, or the NVC was only described in terms of species and not in terms of NVC then a critical load value could not be assigned to the NVC community.

The next step was to extract CBED moorland or woodland nitrogen deposition values (from the 5 x 5 km data) for a single point within each habitat polygon. Cors Bodeilio lies across two of these modelled 5 x 5 km squares and as a result different values are applied to habitat polygons in

different parts of the site, depending on which grid square they lie within. Exceedances were then calculated for each habitat polygon of Cors Bodeilo to which critical loads could be applied.

## **2.16 NITRATE SOURCE APPORTIONMENT MODELLING – ‘FARMSCOPER’ TOOL**

The FarmScoper Tool was applied to two sites by Dr Paul Davison and Dr Heather Williams of Wood Group (previously AMEC Foster Wheeler) under contract to the Environment Agency (Environment Agency, 2018 a,b,c).

Modelling of nitrate within the catchments of Wybunbury Moss (Environment Agency, 2018b) and part of Newbald Becksies (Environment Agency, 2018c) was undertaken, however Cors Bodeilio was not included in this modelling phase. A transferrable approach is also summarised in a stand-alone document *‘Approach for undertaking nitrate source apportionment for wetlands’* (Environment Agency, 2018a).

The modelling tool ‘ADAS FarmScoper’ ([www.adas.uk/service/farmscoper](http://www.adas.uk/service/farmscoper)) (Gooday et al. 2015) was used to estimate nitrate leaching for Wybunbury Moss and Newbald Becksies. FarmScoper is a decision support tool that can be used to assess diffuse agricultural pollutant loads on a farm and quantify the impacts of farm mitigation on these pollutants. This tool was trialled first at Wybunbury Moss and then at Newbald Becksies (Environment Agency, 2018 b;c) however it was not trialled at Cors Bodeilio. FarmScoper requires catchment information and generates predictions of nutrient loadings by sector and pathway.

The modelling of nitrate leaching requires the following; a hydrogeological conceptual model, groundwater and surface water catchments, identification of sources of nitrate (point and diffuse sources), soil type, observed nitrate concentrations in groundwater (provided from Environment Agency & Natural England monitoring data) and validation and interpretation of results (Environment Agency, 2018a). Additional information may come from site managers, catchment walkovers, aerial images, field numbers, livestock numbers and the areas of fields used for agriculture and the type of production (e.g. maize, permanent pasture). Hydrologically effective rainfall is estimated in the FarmScoper tool and total rainfall was obtained from Environment Agency tipping buckets.

The FarmScoper modelling tool was used to provide a prediction of the concentration of nitrate in the soil drainage from each of the sources identified using the methods described above. Where there is no information, land management scenarios can be estimated. The average nitrate concentration in the soil drainage is calculated based on the area of each field and predicted nitrate concentration.

### 3. Site Descriptions

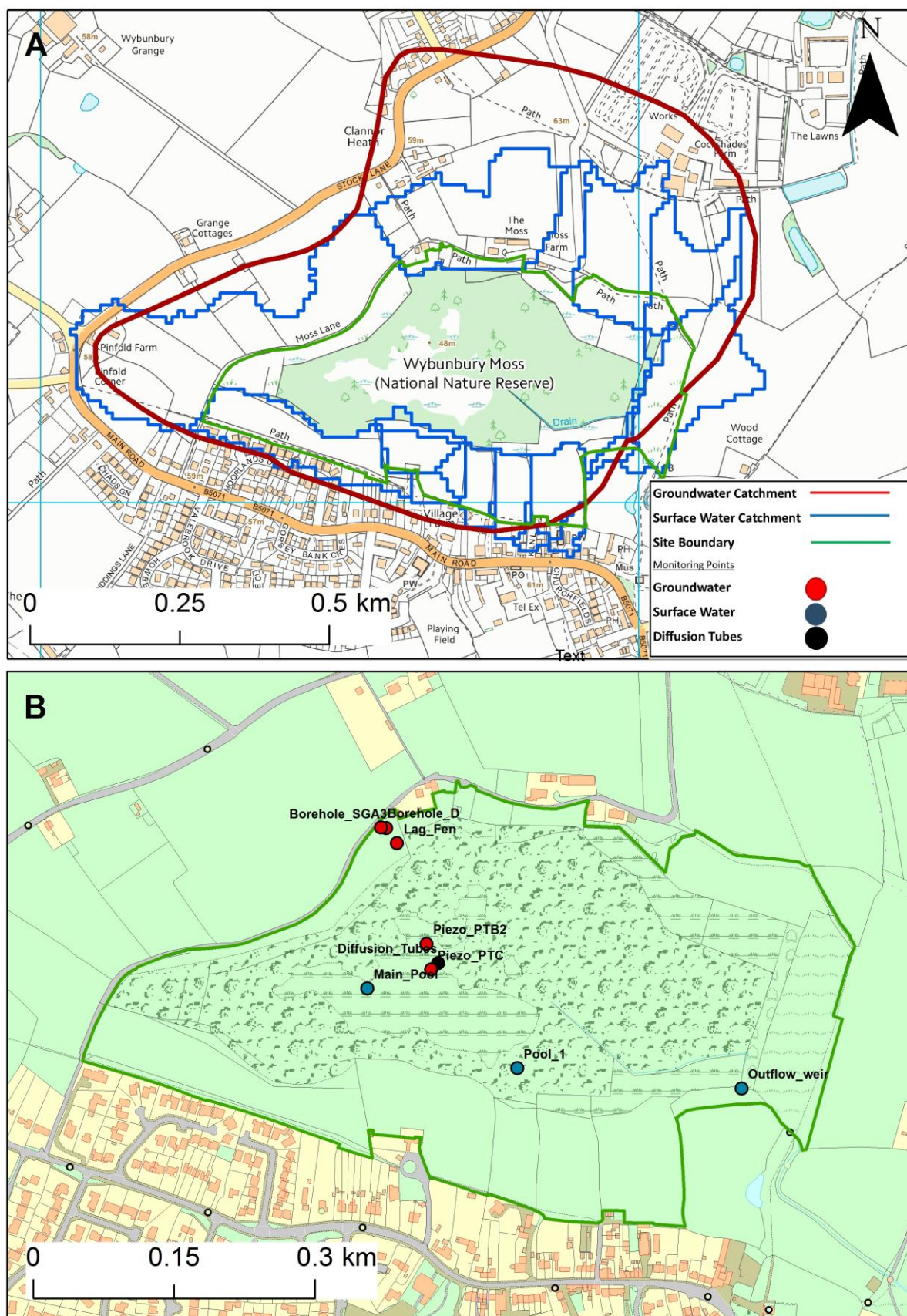
Three study sites were selected; Wybunbury Moss, Newbald Becksies and Cors Bodeilio (Figure 2-1). In order to reduce the costs of this project we utilised pre-existing data from Water Framework Directive targeted investigations including; hydrogeological conceptual models, groundwater chemistry, monitoring networks and vegetation mapping. A short overview of each site, along with some key references are provided in the following sections.

#### 3.1 WYBUNBURY MOSS

Wybunbury Moss (SJ 697 501) is located in the village of Wybunbury in Cheshire, and is designated as a SSSI, SAC and NNR. The wetland (Figure 3-1a&b; Figure 3-2 a&b; Figure 3-3 & Figure 3-4) covers an area of 23 ha and is managed by Natural England. It forms part of the West Midlands Meres & Mosses SAC and the Midland Meres and Mosses Ramsar site. The interest features of the SSSI include buoyant bog, developed as a floating raft, and bog woodland (M2, M2a, M2b, M18, W4), fringed by areas of fen woodland (W2, W5, W6, W6e) and rush pasture and fen meadow (MG10, M22, M23). These habitats support a range of plant species uncommon in Cheshire, as well as an outstanding assemblage of invertebrates including many nationally and locally rare species. Wybunbury Moss has been the focus of various surveys and studies from the 1800s to the present day. Successive vegetation surveys have shown that some rare and uncommon species recorded at Wybunbury Moss have been lost or their populations have declined (Tratt et al. 2015).

Key studies include: Ingram & Seymour, (2003); Moore, (2009); Terradat Ltd, (2009a); Environment Agency, (2011a); Bill Bellamy Associates, (2015); Wheeler et al. (2015); Callaghan, (2015); Tratt et al. (2015); Eades et al. (2015) & Environment Agency, (2018 b).





**Figure 3-1 Wybunbury Moss: groundwater and surface water catchments (A) and monitoring points (B).**  
 Contains OS data. Contains OS data © Crown Copyright and database rights 2019.



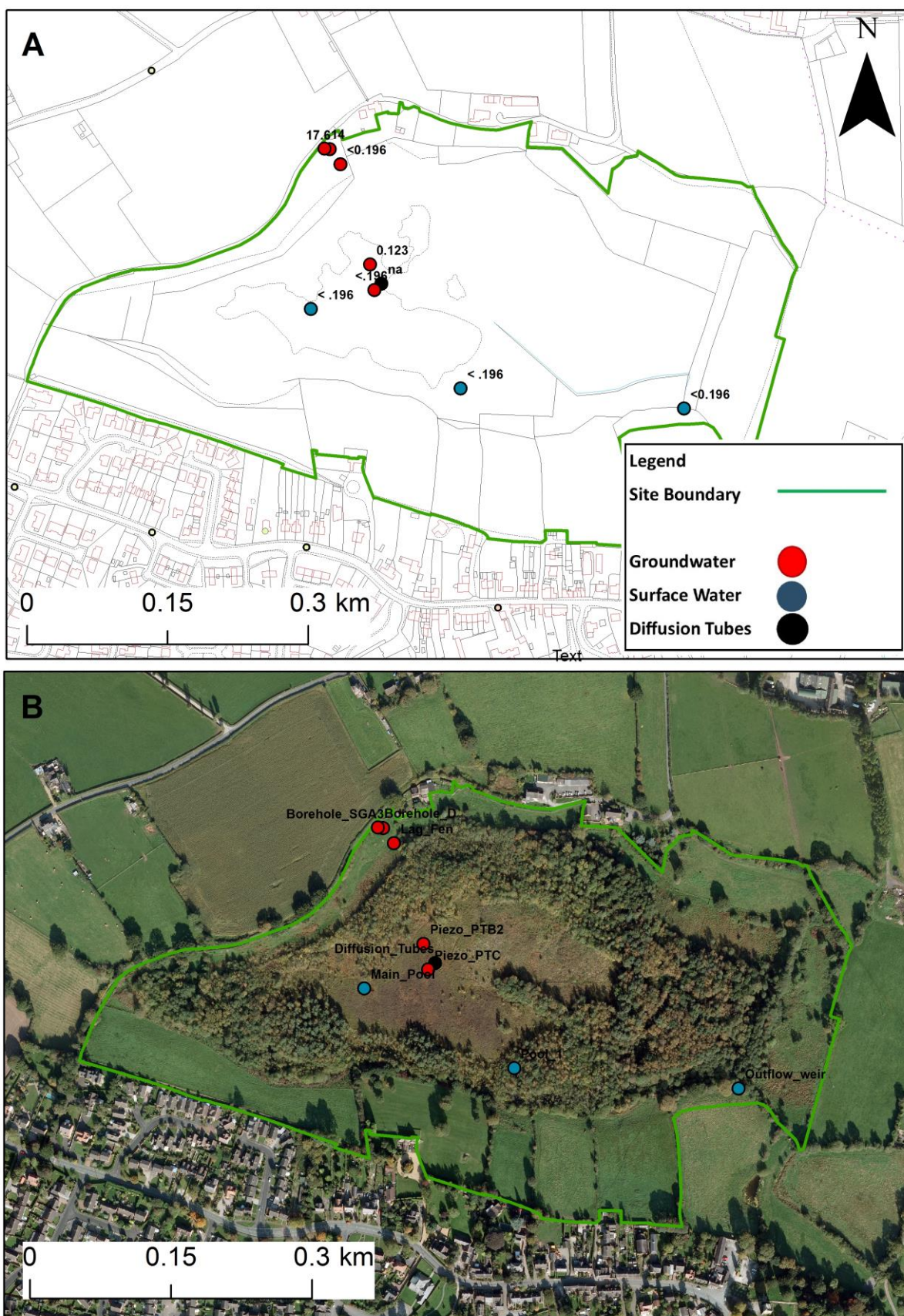
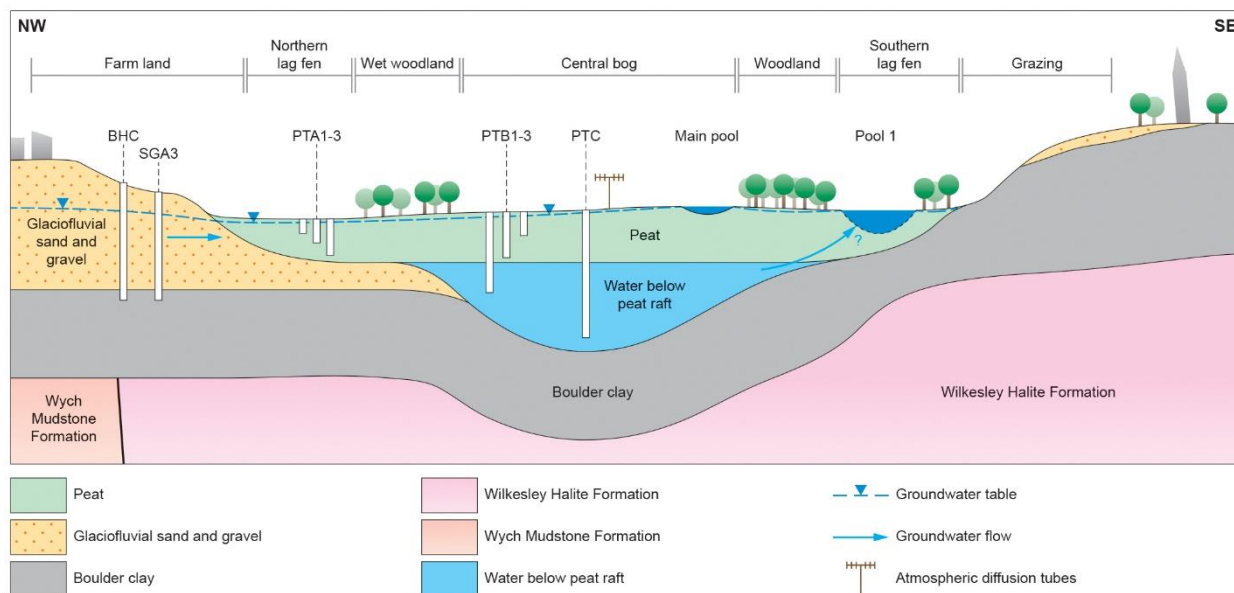
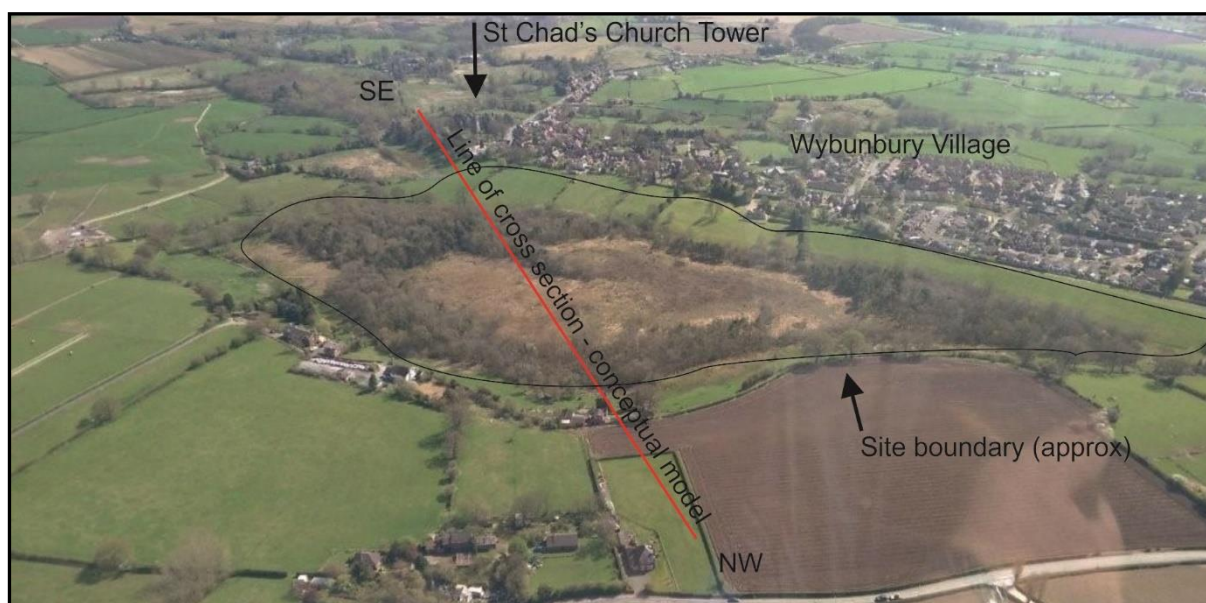


Figure 3-2 Wybunbury Moss map (A) and aerial photograph with monitoring points (B). Contains Ordnance Survey data licence number [100021290 EUL] © Crown Copyright and database rights 2019. Aerial Images © UKP/Getmapping Licence No. UKP2006/01





**Figure 3-3 Wybunbury Moss: schematic conceptual sketch (based on Ingram & Seymour, 2003; Environment Agency, 2011a) not to scale Copyright British Geological Survey © UKRI 2019**



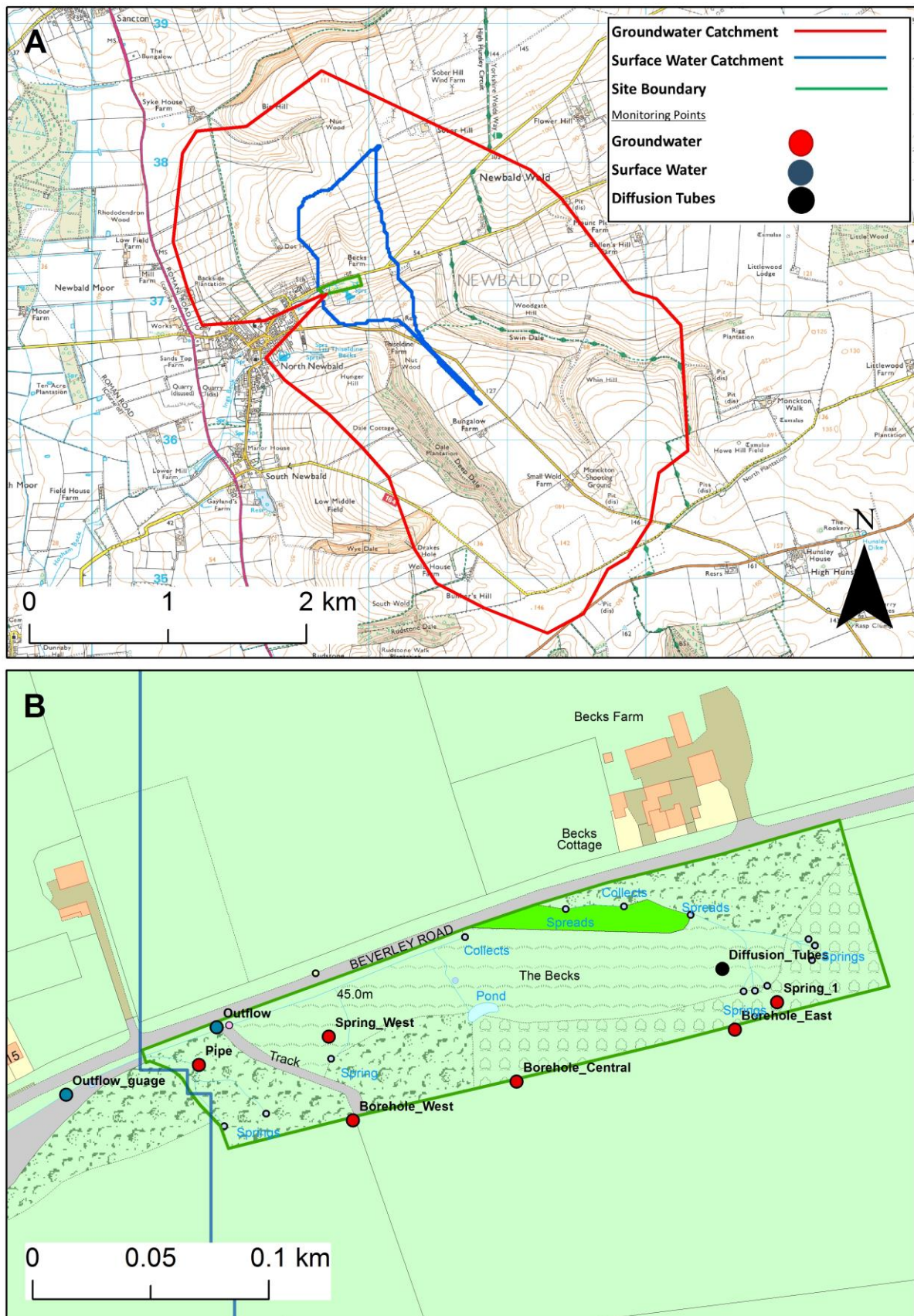
**Figure 3-4 Wybunbury Moss: aerial photograph showing line of conceptual model (Photograph with kind permission of © Geoff Farr)**

### **3.2 NEWBALD BECKSIES**

Newbald Becksies (SE 918 371) is located in the village of North Newbald, Yorkshire and is designated as a SSSI (Figure 3-5 a&b; Figure 3-6 a&b; Figure 3-7 & Figure 3-8). It is a small site, about 2 ha, and is managed by Yorkshire Wildlife Trust. The fen is fed by several chalk springs that issue on its southern margin, supporting a mosaic of habitats from marsh, wet and neutral grassland to tall herb fen vegetation (Natural England SSSI citation<sup>1</sup>). Newbald Becksies is located in an agricultural catchment about 25 km north east from the ‘Drax’ coal fired power station.

Newbald Becksies has been subject to several studies in the past including an assessment of the potential pressure from a public water supply located less than 500 m away (Yorkshire Water Services, 2006; 2007), elevated groundwater nitrates from the chalk aquifer (Environment Agency, 2008; 2011), geophysical investigation (Terradat Ltd, 2009b) and groundwater MODFLOW modelling (Wilkinson, 2009). It is also within the area covered by the regional East Yorkshire Chalk groundwater model, operated by the Environment Agency. Key studies include; Chiverrell, 2004; Yorkshire Water Services, (2006); Yorkshire Water Services, (2007); Terradat Ltd, (2009b), Environment Agency, (2008; 2018c) & Wilkinson, (2009).

<sup>1</sup>Natural England SSSI Citation <https://designatedsites.naturalengland.org.uk/PDFsForWeb/Citation/1005659.pdf>



**Figure 3-5 Newbald Becksies: map, groundwater and surface water catchments (A) and monitoring points (B).** Contains Ordnance Survey data licence number [100021290 EUL] © Crown Copyright and database rights 2019.



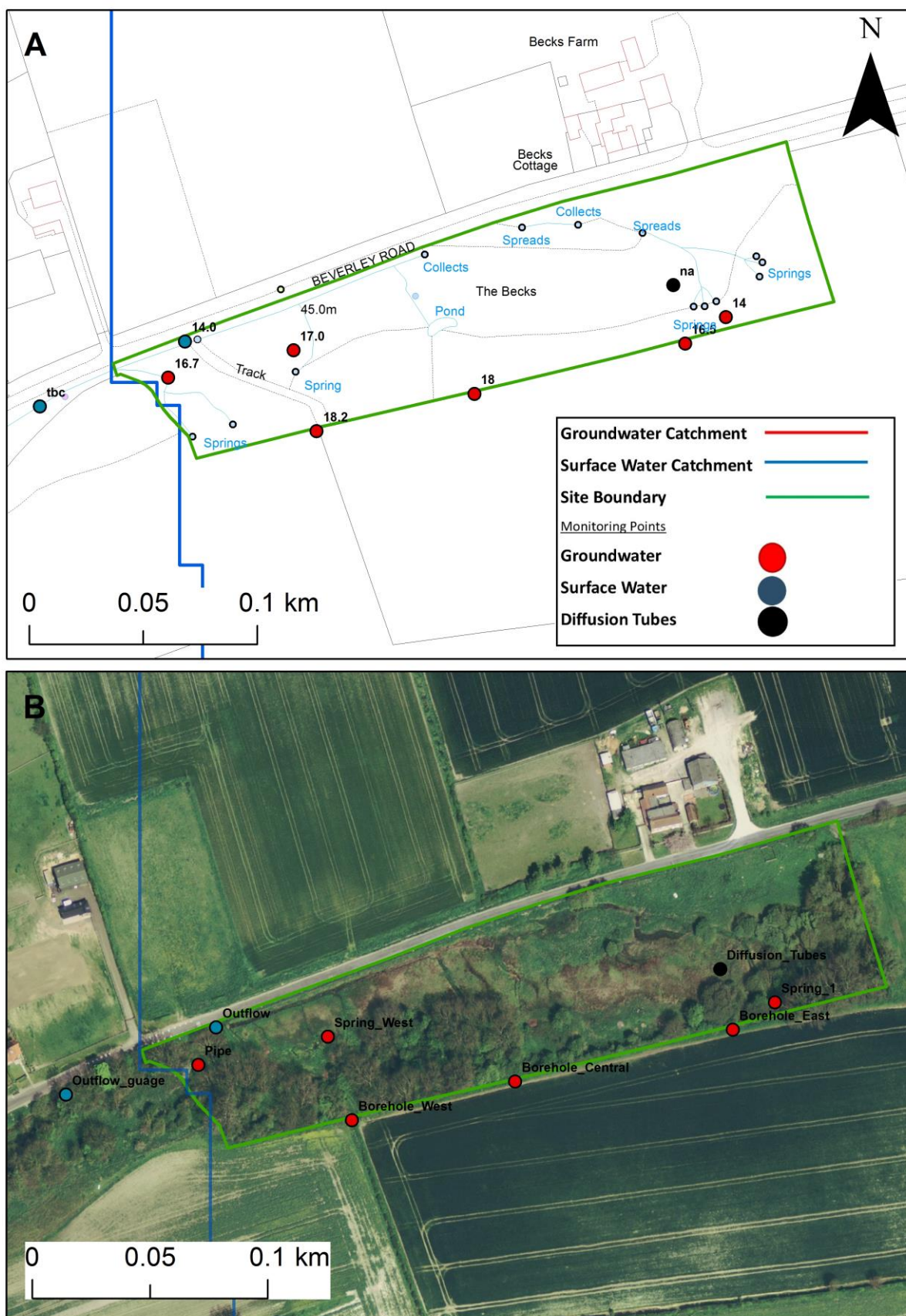
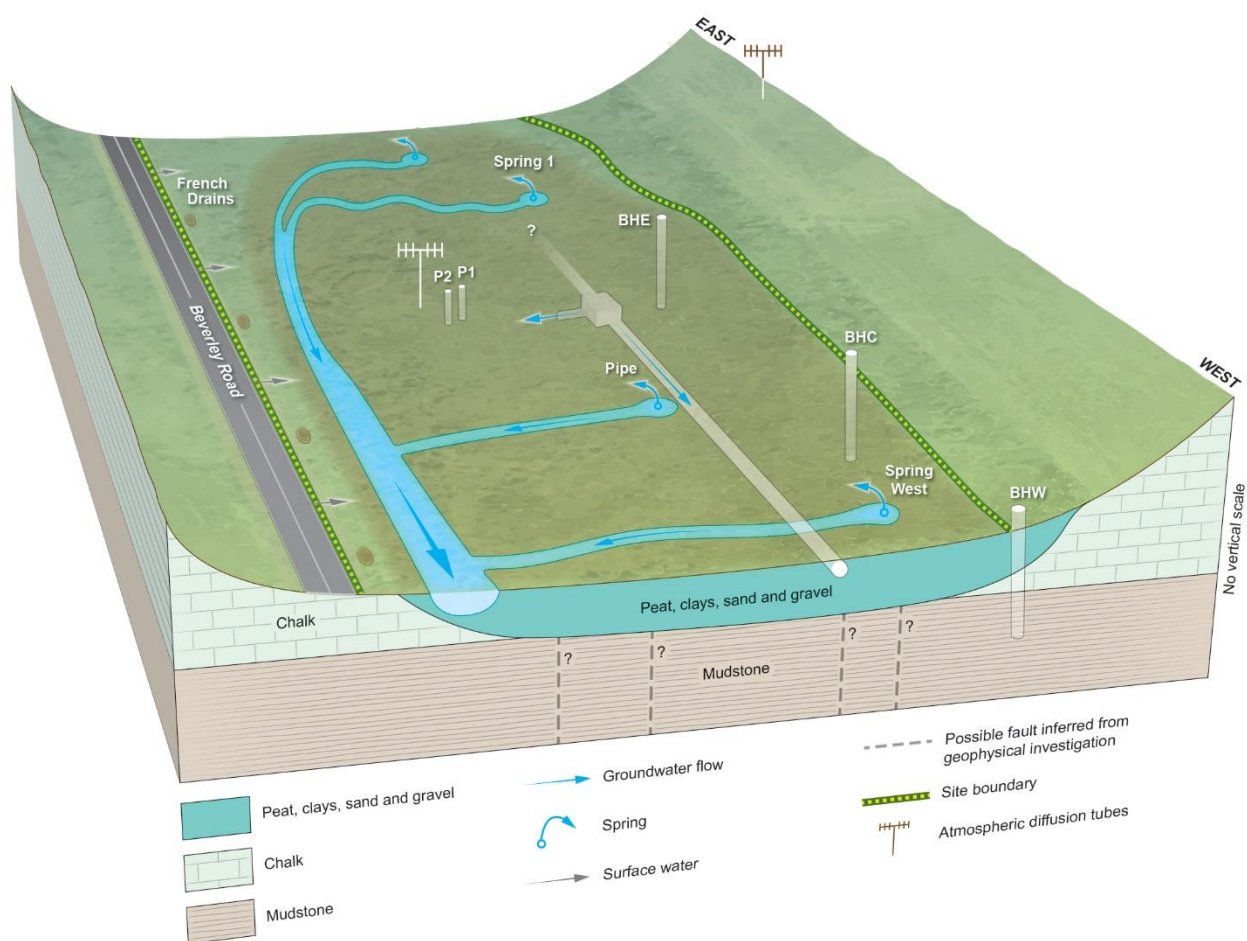


Figure 3-6 Newbald Becksie: map (A) and aerial photograph with monitoring points (B). Contains Ordnance Survey data licence number [100021290 EUL] © Crown Copyright and database rights 2019. Aerial Images © UKP/Getmapping Licence No. UKP2006/01



**Figure 3-7 Newbald Becksies Schematic conceptual sketch NNW-SSE section with view to NEE along Beverley Road (based on Wilkinson, 2009; Terradat, 2009; Environment Agency, 2011b). Not to scale  
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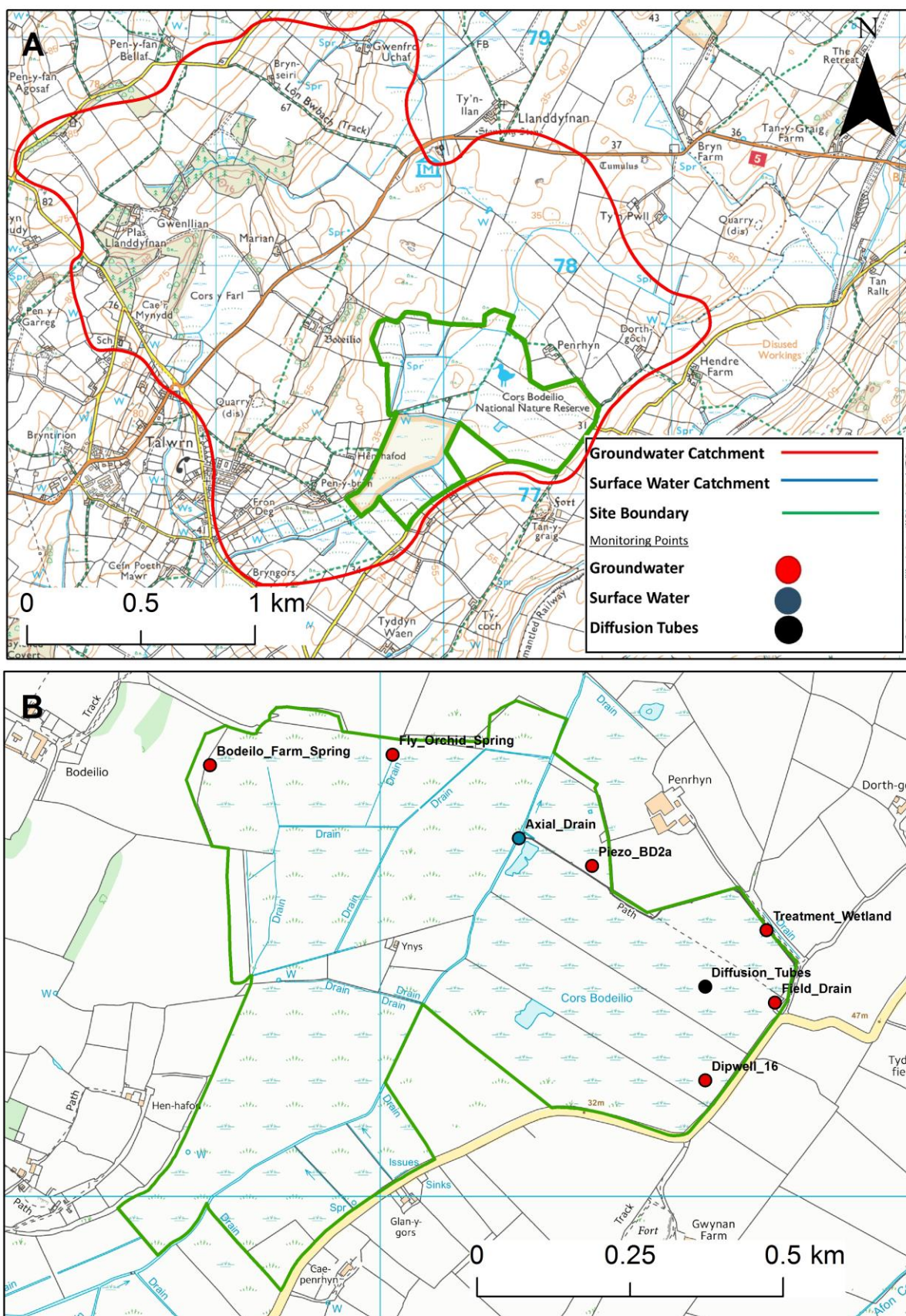
**Figure 3-8 Newbald Becksies view to NNE with Beverley Road to LHS of image. (Photograph with kind permission of © Laura Popely, © Yorkshire Wildlife Trust).**

### 3.3 CORS BODEILIO

Cors Bodeilio (SH 502774) is located west of the village of Pentraeth on the Isle of Anglesey (Figure 3-9 a&b; Figure 3-10 a&b; Figure 3-11 & Figure 3-12). Cors Bodeilio is designated as a SSSI, SAC, NNR and is one of the six wetlands that form the ‘Anglesey and Llyn Fens’ Ramsar site as well as being a component site of the Anglesey Fens SAC. Cors Bodeilio covers an area of 17 ha and is managed by Natural Resources Wales. SAC features include calcareous and alkaline fens and *Molinia* meadows (Countryside Council for Wales, 2008). Cors Bodeilio is dependent upon groundwater from both the underlying Carboniferous Limestone (bedrock) and an overlying sand and gravel aquifer. Its catchment is primarily agricultural.

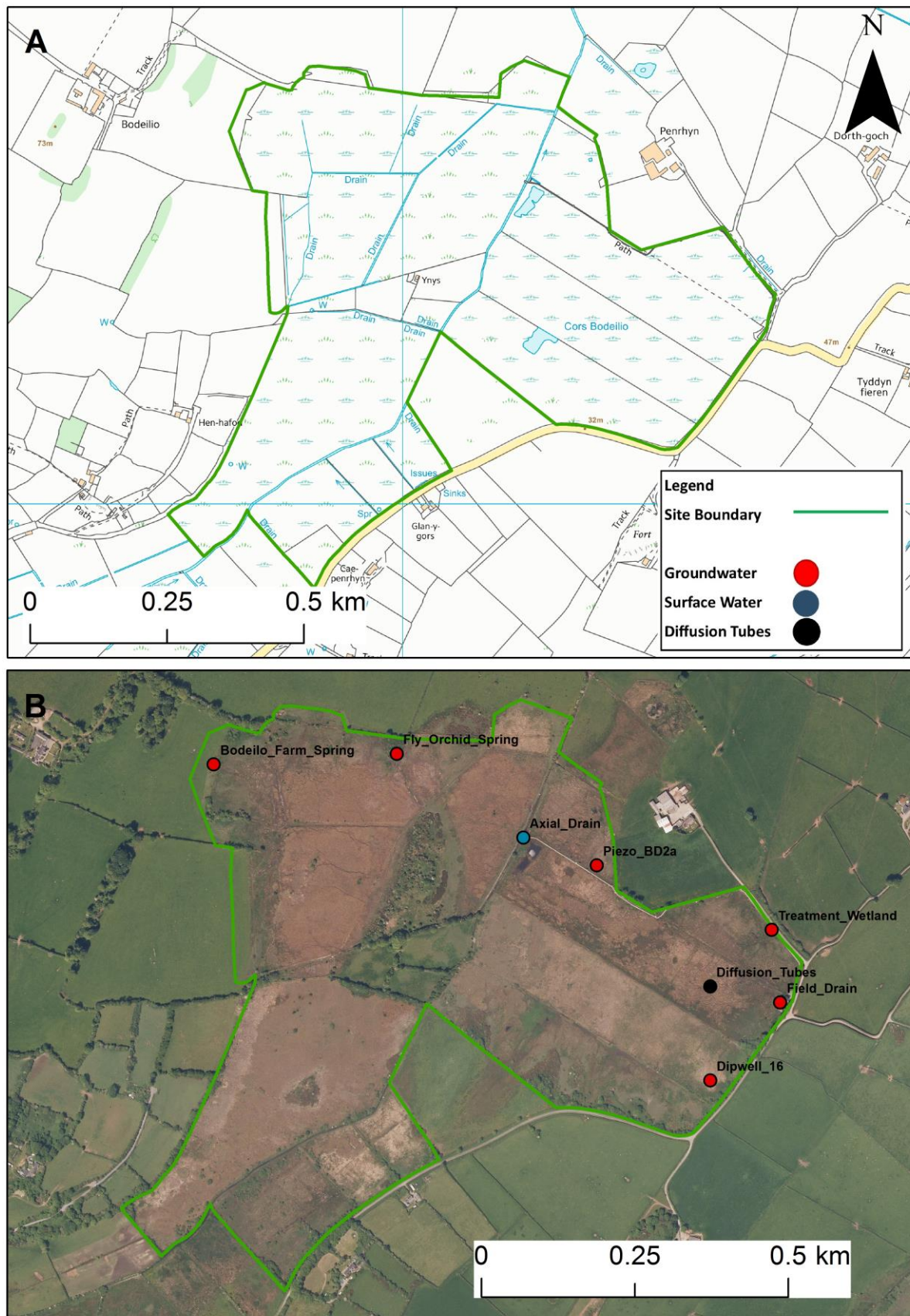
Key studies include; Countryside Council for Wales, (2008); Schlumberger Water Services, (2010); Natural Resources Wales, (2015); outputs from the LIFE Project (07NATUK000948) 2009-2014; West, (2013) and National Vegetation Classification (NVC) Mapping supplied by Natural Resources Wales (Jones, 2018).





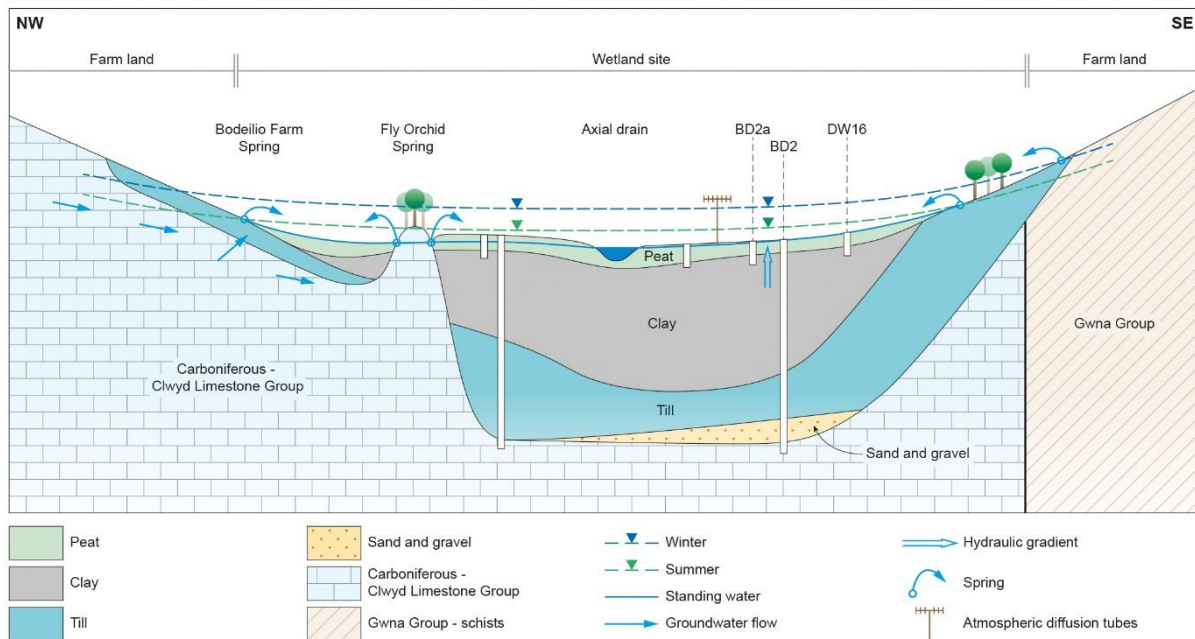
**Figure 3-9 Cors Bodeilio: map, groundwater and surface water catchments (A) and monitoring points (B). Contains OS data. Contains Ordnance Survey data licence number [100021290 EUL] © Crown Copyright and database right 2018.**



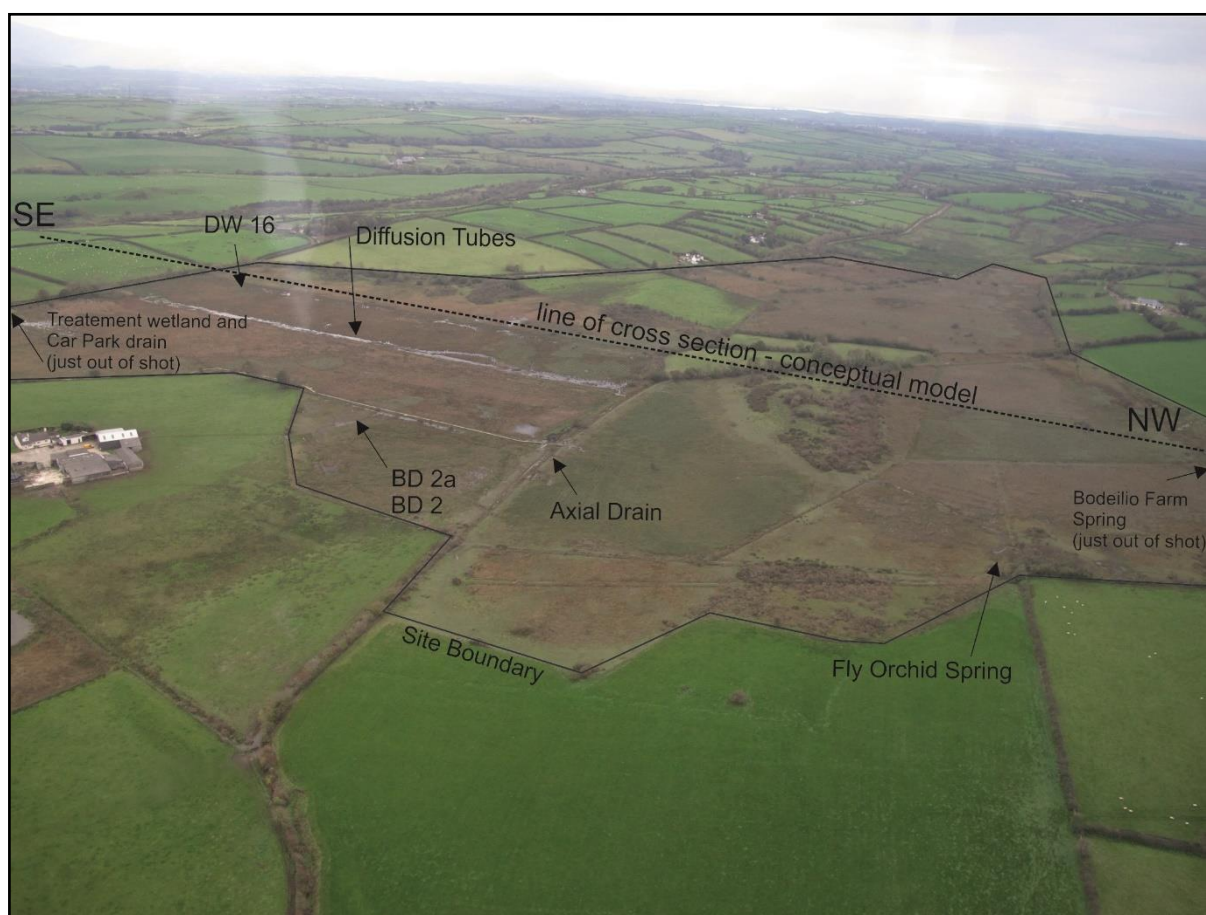


**Figure 3-10 Cors Bodeilio (A) and aerial photograph with monitoring points (B). Contains Ordnance Survey data licence number [100021290 EUL] © Crown Copyright and database rights 2018. Aerial Images © UKP/Getmapping Licence No. UKP2006/01.**





**Figure 3-11 Cors Bodeilio Schematic conceptual model, not to scale. (after and with kind permission of Schlumberger Water Services, 2010).**



**Figure 3-12 Cors Bodeilio aerial photograph, view towards south. Photograph with kind permission of Dr © Peter S Jones, © Natural Resources Wales**

## 4. Results

Data for all three study sites are discussed in this chapter, with the full datasets included in the Appendices. The data comprise both long-term inorganic geochemical sampling (e.g. nitrate), complemented with additional analysis from the intensive one year field campaign including; oxygen and nitrogen isotopes, CFC and SF<sub>6</sub> age dating, fluorescence, on site atmospheric deposition data and the results of modelled loading using the FarmScoper tool. The results are summarised in a table format against relevant targets and thresholds and a decision making tree is provided to help guide future assessments by environmental managers.

### 4.1 INORGANIC WATER CHEMISTRY

**Nitrate trends:** One prerequisite for each site was that there should be a history of inorganic chemical sampling undertaken over several years, confirming that nitrate concentrations in groundwater were greater than relevant WFD threshold value, this is true for all three GWDTEs.

Time series plots show nitrate concentrations during a 7-8 year period for selected monitoring points at each GWDTE (Figure 4-1; Figure 4-2 & Figure 4-3). The nitrate threshold value for peatbogs at any altitude, of 2 mg/l (UKTAG, 2012), is annotated on each graph. Time series data allows us to look at long term trends and provide greater confidence than individual samples. The frequency of data collection was decided locally in response to the requirement of WFD investigations. Where gaps in data exist (e.g. Newbald Becksies) this simply represents time between investigations, where monitoring was reduced or stopped as an efficiency measure.

Wybunbury Moss (Figure 4-1) shows the greatest variation of nitrate-N concentrations, from <1 mg/l within the floating peat (PTB2) to over 20 mg/l in the sand and gravel aquifer (SGA3). These large variations reflect water from two different systems, the sand and gravel aquifer which is within a dominantly agricultural catchment and has the higher nitrate concentrations, whilst the dominantly ombrotrophic (precipitation fed) peat raft has much lower concentrations and complements the conceptual model. Nitrate-N concentrations are well above the drinking water threshold of 11 mg NO<sub>3</sub>-N/l (50 mg/l as NO<sub>3</sub>).

Newbald Becksies (Figure 4-2; Figure 4-2 has persistently high nitrate-N concentrations measured in springs and boreholes within the Chalk aquifer. Although there was a significant gap of several years between the two monitoring periods there appears to have been little reduction of nitrate in the groundwater system. The boreholes (BHE, BHC & BHW) and the spring (Spring1) are both located to the south of the site and all produce similar trends, it is assumed they are all representative of the local Chalk aquifer. Nitrate-N concentrations are well above the drinking water threshold of 11 mg NO<sub>3</sub>-N/l

Cors Bodeilio (Figure 4-3) has the lowest overall nitrate-N concentrations of the three sites in this study, possibly a result of less intensive agriculture within its catchment. Springs and piezometers monitor the Carboniferous Limestone and overlying sand and gravel aquifer, both of which contribute water to the site. Long term monitoring shows a general decrease in nitrate after 2008 with an general increase after 2013 (e.g. monitoring locations; 'Bodeilio Farm Pond' and 'Fly Orchid Spring'). The drivers of this change in nitrate concentrations are not known however one possible theory is that it could be a response in groundwater nitrate concentrations related to a decrease in fertiliser application during and following the 2008 economic recession - although this is purely speculative.

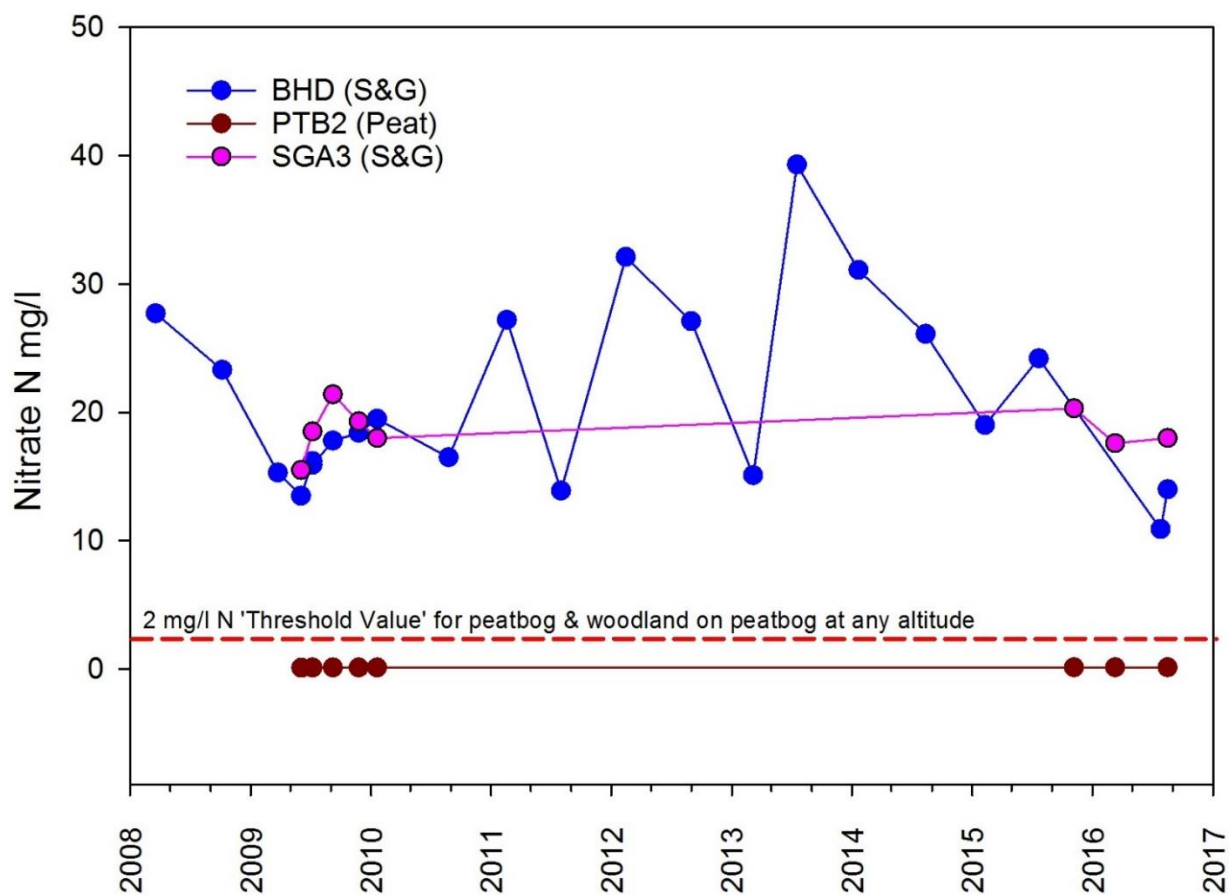


Figure 4-1 Wybunbury Moss Nitrate N mg/l 2009 to 2016

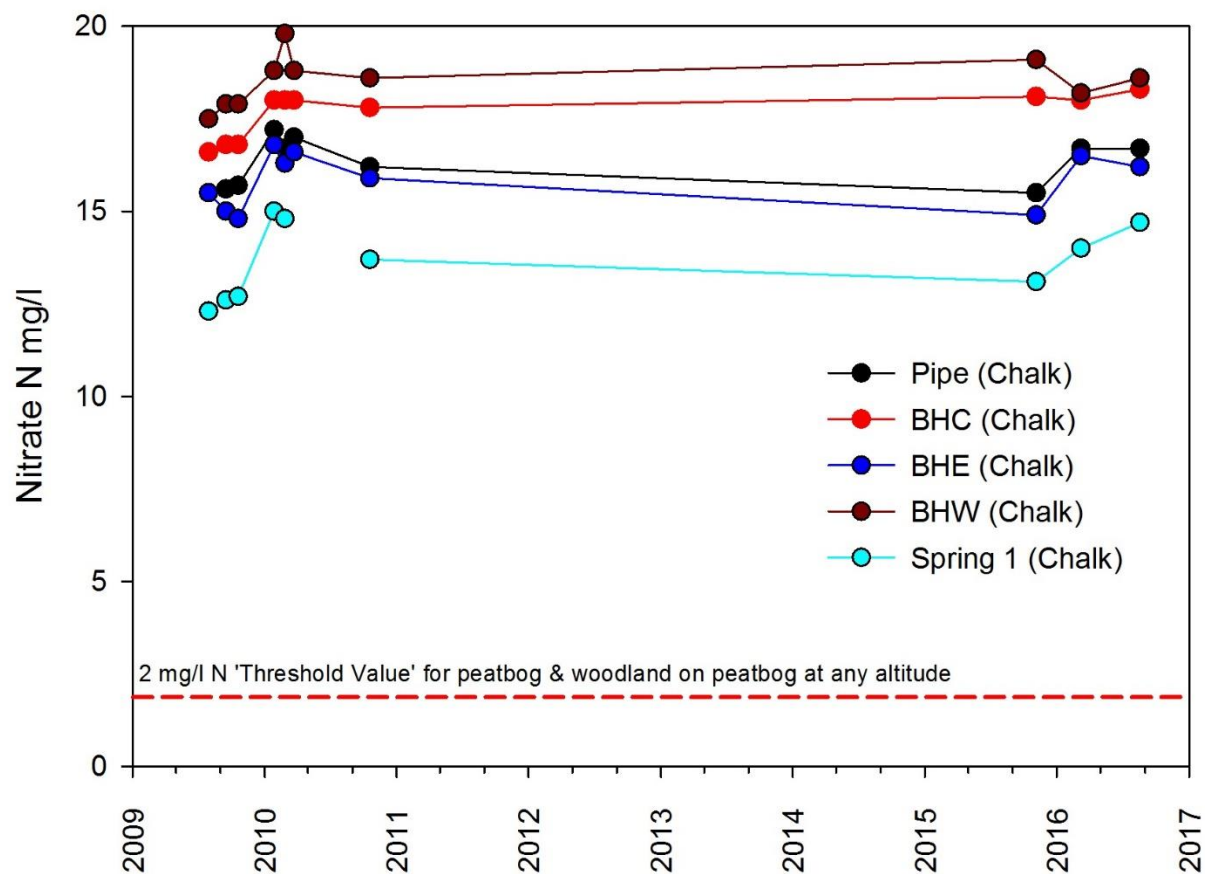


Figure 4-2 Newbald Becksies. Nitrate N mg/l 2009 to 2016

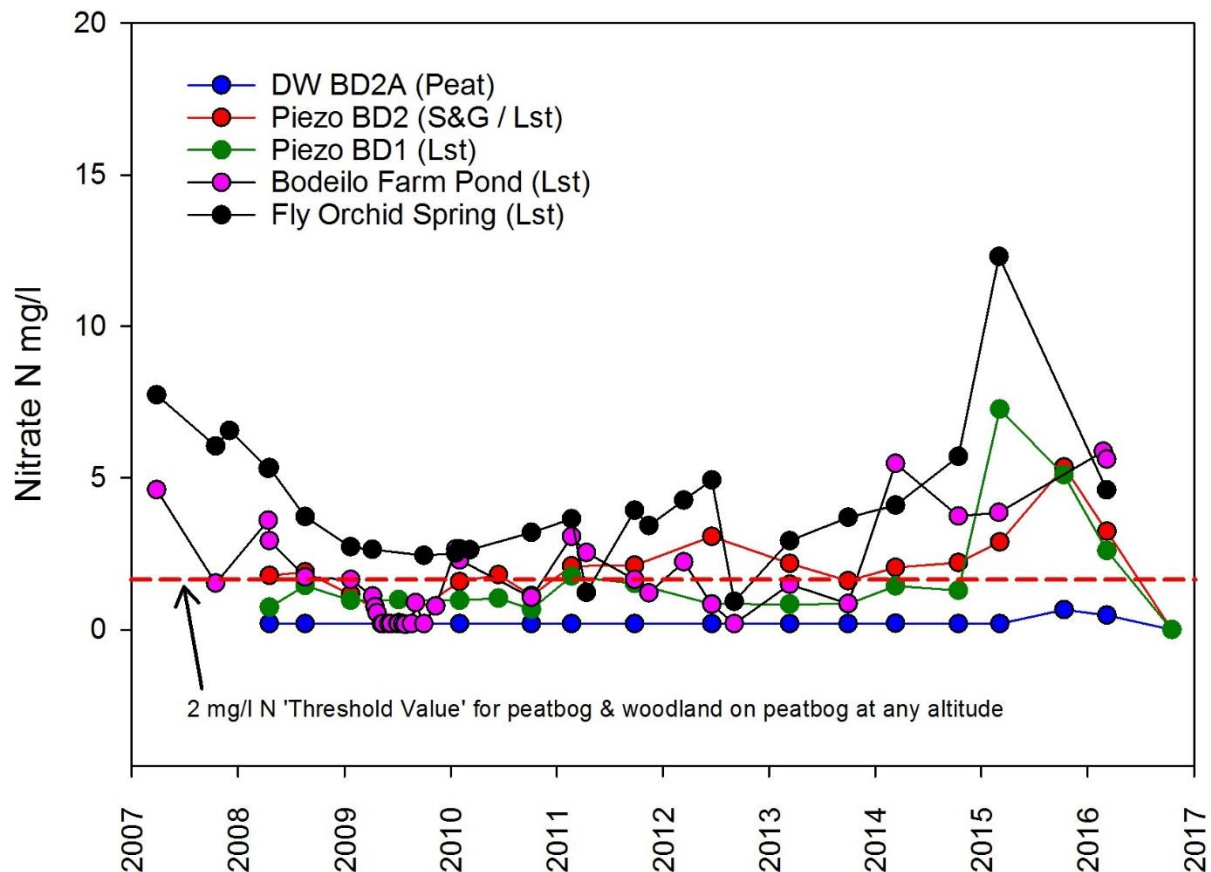


Figure 4-3 Cors Bodeilio Nitrate N mg/l (2007 to 2016)

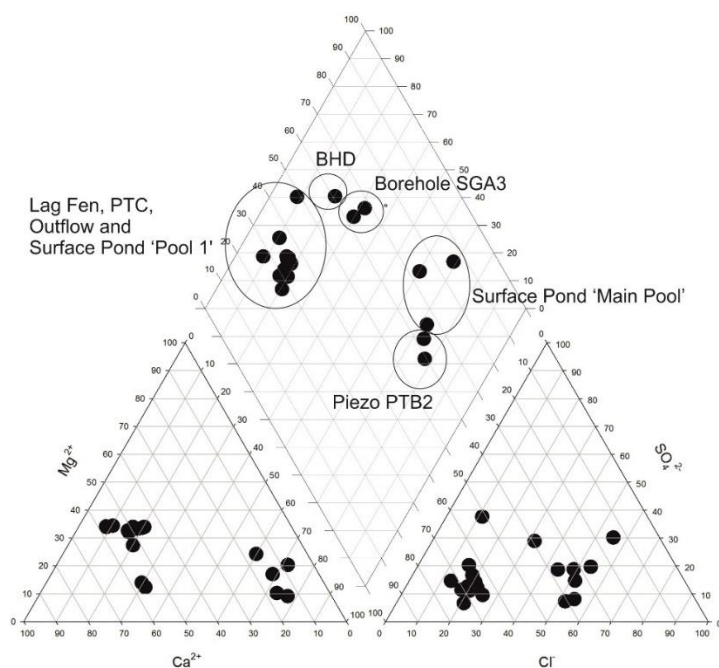
**Piper Diagrams:** The major ions (cations and anions) from samples collected between 2015-2016 are plotted on Piper diagrams (Figure 4-4 Figure 4-5 & Figure 4-6). Piper diagrams can be used to look at the ionic composition of a water sample and define water facies (types). This information can be used to improve the conceptual model. All three sites have a dominantly calcium bicarbonate water type. Newbald Becksies shows the least variation between samples (Figure 4-5) suggesting that all the water at Newbald Becksies originates from a similar/same aquifer. Cors Bodeilio also shows that samples are of a similar ionic composition, suggesting a similar source (Figure 4-6).

Wybunbury Moss (Figure 4-4) shows a wider range of water types or facies, in part due to the varying geological location and type of sampling points. The Piper diagram helps us to start to address one of the questions that has persisted at the site, which is, what if any interaction occurs between the high nitrate sand and gravel aquifer and the low nitrate water within and below the peat raft ? (see Wheeler et al. 2015 page 37-38 for most up to date discussion). The Piper diagram shows for the first time that the ionic composition of the water in the sand and gravel aquifer (SGA3) is similar to the water below the peat raft (PTC), both dominated with calcium and bicarbonate/chloride ions. However nitrate concentration does vary between the sand and gravel aquifer ( $> 20$  mg/l) and below the peat raft ( $<1$  mg/l), and this could represent a zone of denitrification rather than a physical barrier to water movement as suggested in earlier conceptual models (e.g. EA, 2010).

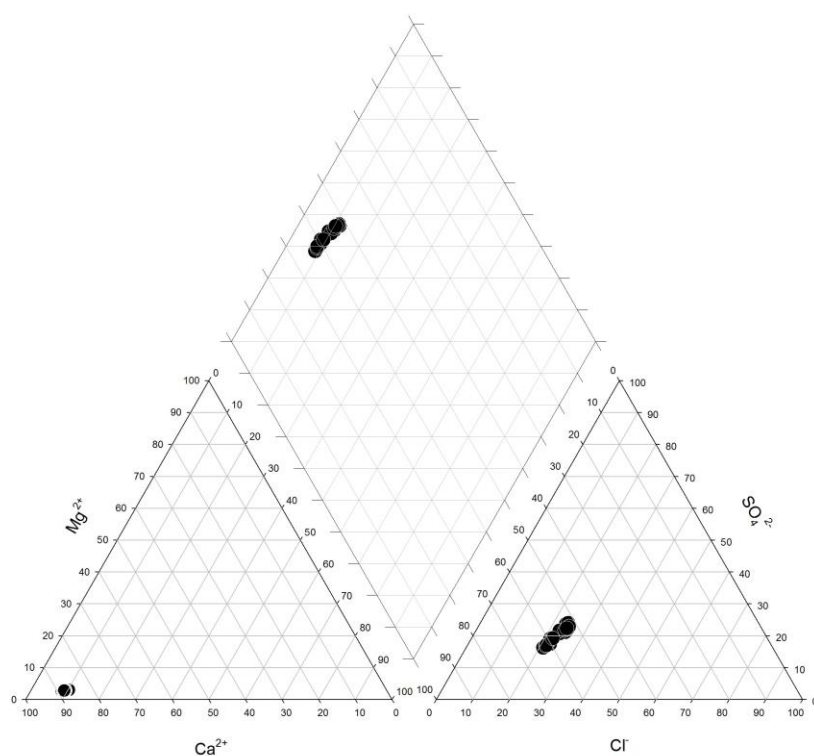
The diagram also illustrates the difference between the water chemistry in the sand and gravel aquifer and the water directly in/on the floating peat raft (PTB2; Main Pool) both of which trend towards the sodium chloride type, suggesting the dominant water supply mechanism to the floating peat raft is precipitation. Using this information we can support our conceptual understanding that water supply to the main part of the peat raft is dominated by precipitation and that there may be some similarities between water in the sand and gravel aquifer and water below the peat raft.



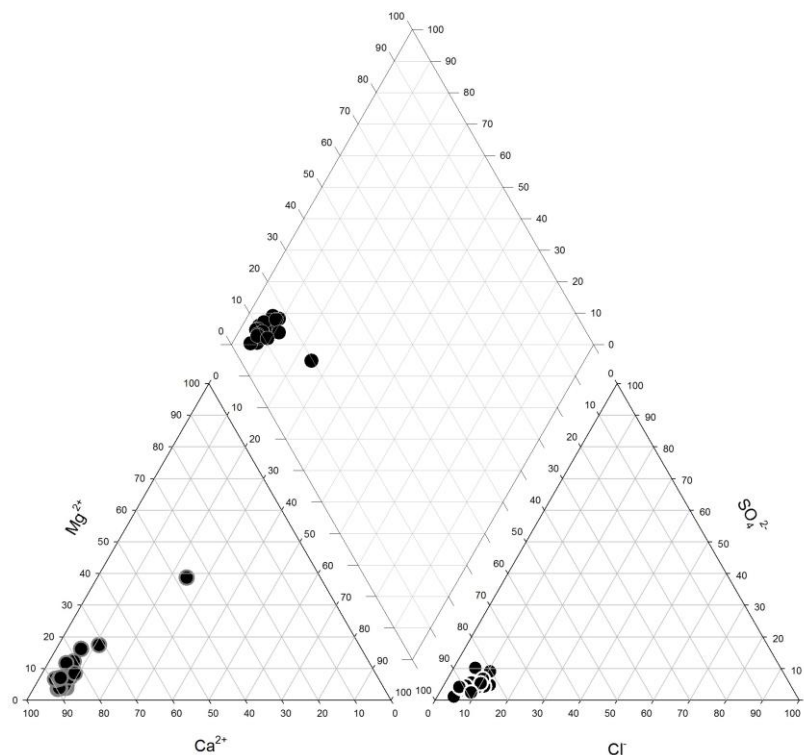
Differences in nitrate concentration between the sand and gravel (high concentration) and water under the peat raft (low concentration) need further consideration, the difference may be the result of denitrification, and future site investigations should look at this possibility.



**Figure 4-4 Wybunbury Moss Piper Diagram (2015-2016)**



**Figure 4-5 Newbald Becksies Piper Diagram (2015-2016)**



**Figure 4-6 Cors Bodelio Piper Diagram (2015-2016)**

## 4.2 OXYGEN AND NITROGEN ISOTOPES

Different sources of nitrogen can have a wide range of  $\delta^{15}\text{N}_{\text{NO}_3}$  and  $\delta^{18}\text{O}_{\text{NO}_3}$  values and these ratios will vary in atmospheric deposition (wet and dry), fertilizers, animal and human waste, soils (Kendall & McDonnell, 1998; Kendall, et al. 2007).  $\delta^{15}\text{N}_{\text{NO}_3}$  and  $\delta^{18}\text{O}_{\text{NO}_3}$  have been used to identify sources of nitrate in large catchment studies (Pasten-Sapate, 2013; Saccon et al. 2013 & Urresti et al. 2015) and also for smaller targeted WFD investigations in England and Wales (Schlumberger Water Services 2010; Whiteman et al. 2017).

Figure 4-7 plots the proportions of  $\delta^{15}\text{N}_{\text{NO}_3}$  and  $\delta^{18}\text{O}_{\text{NO}_3}$  for all three GWDTEs within this study. Groundwater and surface waters were sampled at each GWDTE (Table 2), however no rainfall samples were analysed for oxygen or nitrogen isotopes. ‘Kendall boxes’ are annotated onto the graph in Figure 4-7 and are used to illustrate the possible source of nitrate. However isotope data and Kendall boxes must not be relied upon by themselves to define the source of nitrate in a sample and interpretation must be undertaken using a well-developed conceptual model and complementary spatial and temporal inorganic chemical analysis.

The majority of samples from the GWDTEs fall within the lower left hand Kendall box, which suggests the dominant source of nitrate at all three sites is from nitrification of ammonium in soils or direct from fertilizers. Nitrate sourced from manure and/or septic tanks is suggested by data points that plot in the bottom right hand corner of Figure 4-7. Where precipitation acts as a dominant pathway then the results plot higher up the y axis. This is illustrated by two samples on Figure 4-7, Cors Bodelio (Site: DW16) which is a shallow peat piezometer (<2 m deep) and Wybunbury Moss (Site: Pool M1) which is an open pool on the surface of the bog. The samples from Newbald Becksies all group very closely together, especially when compared to the wider distribution of samples from Wybunbury Moss and Cors Bodelio. The similarity in results from Newbald Becksies is not surprising as they are all from the same groundwater system (Chalk aquifer) and there were no surface water samples collected, as there were from bog pools at Wybunbury. The similarity in water types at Newbald Becksies are also reflected by the inorganic water chemistry.

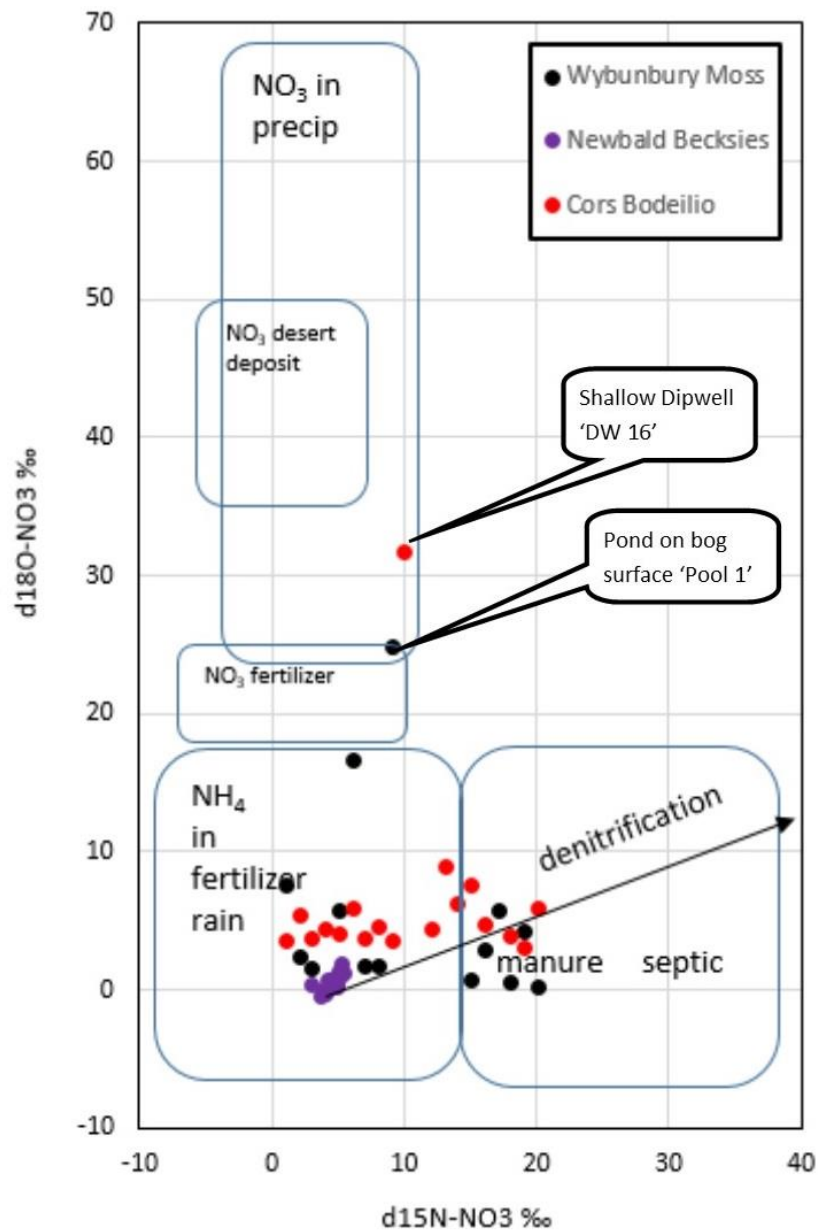


Figure 4-7 Nitrogen and Oxygen Isotopes from groundwater and surface water samples (see Table 2 for sample sites and Appendices for results) Background chart and boxes from Kendall & McDonnell, 1998.

### 4.3 CFC AND SF<sub>6</sub> AGE DATING

It is possible when groundwater discharges at a GWDTE that it is several years or even decades old and it means that nitrate in the system may result from land use activities in the past. This time delay is often referred to as the 'Nitrate Time Bomb', and modelling suggests that in some areas it may take 60 years for peak nitrate to occur (Wang et al. 2012). Defining the age of groundwater is important as it allows us to approximately determine when nitrates entered the groundwater system, and thus how long it may take to realise a reduction in nitrates as a result of land use changes (e.g. reduction in application of fertilisers).

Chlorofluorocarbons (CFCs) and sulphur hexafluoride (SF<sub>6</sub>) are a useful tool that can provide dates for the recharge of modern (i.e. < 60 years) groundwater (e.g. Gooddy et al. 2005). CFC and SF<sub>6</sub> have been successfully used to provide recharge data for groundwater in numerous GWDTE studies (e.g. Schlumberger Water Services, 2010a; 2010b; Whiteman et al. 2017) and offer a useful method for dating groundwater and for use in pollution risk assessments (Darling et al. 2012). As with any method there are factors that can influence the results including; the movement of gases within the unsaturated zone, excess air, degassing, contamination, and microbial breakdown (Darling et al. 2012) and care needs to be taken when collecting samples for analysis.

Successful sampling requires the ability to obtain a water sample without modern atmospheric interaction. Thus boreholes where groundwater can be sampled using an in-situ pump are ideal however surface waters should be avoided due to the degree of mixing with the atmosphere. Sampling at springheads is possible using a small portable pump to directly abstract water before contact with the atmosphere.

Three CFC and SF<sub>6</sub> samples were collected at each of the GWDTEs in this study (Table 3; Table 4) from both boreholes and springheads. The data is useful and allows us to put a time range on the age of groundwater at a borehole or spring and to improve the site conceptual model. However date ranges rather than absolute dates are often produced, this may be due to mixing of older groundwater with a more modern recharge component.

Groundwater at Wybunbury Moss is the oldest of the three study sites; ranging between 1959 and modern with the oldest water measured under the main body of the bog. Groundwater in the sand and gravel aquifer produced an age range of 1970s to modern and the effect of a nitrate time lag should also be considered when implementing land use changes near Wybunbury Moss.

Groundwater at Newbald Becksies ranged between 1974 and modern, from the Chalk Aquifer and the effect of a nitrate time lag should also be considered when implementing land use changes near Newbald Beckises as some of the nitrate may be a result of past and not current land use practices.

Groundwater at Cors Bodeilio is the youngest of the sites ranging between 1985 and modern. Although nitrate concentrations are also lowest at Cors Bodeilio it does suggest that any land use changes to reduce nitrate could be realised over a period of years rather than decades.



**Table 3 CFC and SF6 results**

Site	Sample Point	pmol/L	pmol/L	fmol/L	Modern Fraction		
		CFC-12	CFC-11	SF6	CFC-12	CFC-11	SF6
Wybunbury	Borehole SGA3	0.634	5.517	2.826	0.231	1.196	0.877
Wybunbury	Piezo PTC	0.146	0.577	21.001	0.053	0.125	6.513
Wybunbury	Piezo B2	0.676	0.317	0.262	0.246	0.069	0.081
Newbald Becksies	Borehole East	3.599	11.998	1.253	1.311	2.602	0.389
Newbald Becksies	Spring West	3.806	11.464	0.429	1.386	2.486	0.133
Newbald Becksies	Spring 1	2.839	7.995	0.400	1.034	1.734	0.124
Cors Bodeilio	Farm Pond Spring	3.631	9.293	1.651	1.323	2.015	0.512
Cors Bodeilio	Piezo BD2A	2.121	4.107	2.575	0.773	0.891	0.799
Cors Bodeilio	Fly Orchid Spring	3.242	9.679	0.983	1.181	2.099	0.305

**Table 4 CFC and SF6 year of recharge**

Site	Sample Point	Year of Recharge		
		CFC-12	CFC-11	SF6
Wybunbury	Borehole SGA3	1970	>modern	2011
Wybunbury	Piezo PTC	1959	1966	>modern
Wybunbury	Piezo B2	1970	1963	1979
Newbald Becksies	Borehole East	>modern	>modern	1994
Newbald Becksies	Spring West	>modern	>modern	1982
Newbald Becksies	Spring 1	1974	1973	1982
Cors Bodeilio	Farm Pond Spring	>modern	>modern	1998
Cors Bodeilio	Piezo BD2A	1986	1985	2008
Cors Bodeilio	Fly Orchid Spring	>modern	>modern	1991

#### 4.4 FLUORESCENCE

The fluorescence dissolved organic matter (fDOM) results (Table 5) from Wybunbury Moss and Cors Bodeilio confirm the high humic and fulvic-like concentrations, typical of peat formation waters. Exceptions to this are found at Cors Bodelio sites, Piezo BD2A and Fly Orchid Spring, both of which represent the Carboniferous Limestone and thus have no/limited groundwater supply from peat waters, supporting the conceptual model (WMC, 2008). In addition, the fDOM results from 'Borehole Central' at Newbald Becksies suggest a mixture of peat and Chalk groundwater sources.

A combination of the N, P and tryptophan chemistry, which can be used as an indicator for organic pollution, suggest that these sites are not likely to be impacted by significant sewerage inputs. However the limited spatial and temporal distribution of the samples should be noted thus not ruling out sewage impact in areas that have not been sampled. Much higher Fulvic-like: Tryptophan-like ratios, i.e. >2 would be expected as well as much higher P concentrations and N:P ratios if this was the case.

This method offers a rapid and affordable way to identify sewerage inputs into the groundwater system of wetlands, and confirms the interaction of groundwater with humic layers (peat) thus can help to support the development of and improvement of the hydrogeological conceptual model.

**Table 5 Fluorescence results**

Site	Sample Point	Geology	Nitrate	Orthophosphate	Suspect	Fulvic-like (Raman Units)	Tryptophan-like (Raman Units)	Fluorescence index (FI)	Freshness Index $\beta:\alpha$	Humification index (HI)
			mg/l (as N)	as P mg/l	sewage imput					
Wybunbury Moss	Borehole B2	Chalk	n/a	n/a	no	30.2	6.5	24.0	6.8	132.6
Wybunbury Moss	Lag Fen	Sand and Gravel and Peat	0.988	< .004	no	3.2	0.8	1.4	0.5	22.3
Wybunbury Moss	Main Pool	Sand and Gravel and Peat	< .004	0.032	no	3.5	0.8	5.6	1.7	46.9
Wybunbury Moss	Pool M1	Peat	< .004	< .004	no	4.7	0.8	1.3	0.4	20.2
Wybunbury Moss	Piezo PTC	Peat (below floating peat)	<.196	0.109	no	3.6	1.2	1.3	0.5	10.3
Wybunbury Moss	Borehole SGA3	Sand & gravel	17.6	< .004	no	3.8	1.1	1.4	0.6	15.3
Wybunbury Moss	Main drain at weir	Peat, Sand & Gravel	< .004	0.106	no	7.2	1.5	5.5	2.1	96.7
Newbald Becksies	Borehole Central	Peat	18	<0.2	no	0.9	1.0	1.5	0.7	2.2
Newbald Becksies	Borehole East	Chalk	16.5	<0.2	no	0.5	0.4	2.1	0.7	3.1
Newbald Becksies	Borehole West	Chalk	18.2	<0.2	no	0.5	0.3	1.6	0.9	4.9
Newbald Becksies	Pipe	Chalk	16.7	<0.2	no	0.6	0.6	1.8	0.8	2.8
Newbald Becksies	Spring 1	Peat and Chalk	14	<0.2	no	0.4	0.4	1.8	0.7	3.8
Cors Bodeilio	Piezo BD2A	Limestone	<0.2	<0.2	no	0.6	0.3	1.5	0.6	4.3
Cors Bodeilio	Pipe	PreCambrian bedrock	n/a	n/a	no	1.1	0.5	2.0	0.6	6.9
Cors Bodeilio	Bodeilio Farm Spring	Sand & Gravel / Limestone	7.74	<0.2	no	1.0	0.4	1.6	0.6	6.8
Cors Bodeilio	Main drain at bridge	Peat, Sand & Gravel, Limestone	<0.2	<0.2	no	2.1	0.5	1.3	0.5	18.2
Cors Bodeilio	Treatment wetland	PreCambrian bedrock	n/a	n/a	no	1.7	0.5	1.3	0.5	15.6
Cors Bodeilio	Fly Orchid Spring	Sand & Gravel / Limestone	5.71	<0.2	no	0.7	0.7	1.4	0.6	3.1

**Table 6 Absorbance results**

Site	Sample Point	Geology	Nitrate	Orthophosphate	Suspect	ABS240	ABS270	ABS340	ABS410
			mg/l (as N)	as P mg/l	sewage imput				
Wybunbury Moss	Borehole B2	Chalk	0.988	< .004	no	8.5	6.6	2.9	1.1
Wybunbury Moss	Lag Fen	Sand and Gravel and Peat	< .004	0.032	no	0.3	0.2	0.1	0.0
Wybunbury Moss	Main Pool	Sand and Gravel and Peat	< .004	< .004	no	0.9	0.7	0.3	0.1
Wybunbury Moss	Pool M1	Peat	18	<0.2	no	1.0	0.7	0.3	0.1
Wybunbury Moss	Piezo PTC	Peat (below floating peat)	<.196	0.109	no	0.5	0.3	0.1	0.0
Wybunbury Moss	Borehole SGA3	Sand & gravel	17.6	< .004	no	0.4	0.2	0.1	0.0
Newbald Becksies	Main drain at weir	Peat, Sand & Gravel	< .004	0.106	no	1.1	0.8	0.3	0.1
Newbald Becksies	Borehole Central	Peat	16.5	<0.2	no	0.2	0.1	0.0	0.0
Newbald Becksies	Borehole East	Chalk	18.2	<0.2	no	0.2	0.0	0.0	0.0
Newbald Becksies	Borehole West	Chalk	16.7	<0.2	no	0.2	0.0	0.0	0.0
Newbald Becksies	Pipe	Chalk	14	<0.2	no	0.2	0.0	0.0	0.0
Cors Bodeilio	Spring 1	Peat and Chalk	n/a	n/a	no	0.1	0.0	0.0	0.0
Cors Bodeilio	Piezo BD2A	Limestone	<0.2	<0.2	no	0.1	0.0	0.0	0.0
Cors Bodeilio	Pipe	PreCambrian bedrock	n/a	n/a	no	0.1	0.1	0.0	0.0
Cors Bodeilio	Bodeilio Farm Spring	Sand & Gravel / Limestone	7.74	<0.2	no	0.1	0.1	0.0	0.0
Cors Bodeilio	Main drain at bridge	Peat, Sand & Gravel, Limestone	<0.2	<0.2	no	0.3	0.2	0.1	0.0
Cors Bodeilio	Treatment wetland	PreCambrian bedrock	n/a	n/a	no	0.2	0.1	0.1	0.0
Cors Bodeilio	Fly Orchid Spring	Sand & Gravel / Limestone	5.71	<0.2	no	0.1	0.1	0.0	0.0

**Footnote for Table 5 & 6 :** Units for Fulvic-like and tryptophan-like are all in Raman Units (RU) – normalised to the water Raman peak (Stedmon et al. 2003), ABS240 (m-1), the other metrics are ratios so are unitless. FI=Fluorescence index and HI= Humification index. (i) the fluorescence index (FI) which is commonly used to differentiate between terrestrial and microbial DOM sources (McKnight et al. 2001), (ii) the humification index (HIX), an indication of humicity, and the condensing of fluorescing molecules (Zsolnay et al. 1999); (iii) the “freshness index”  $\beta:\alpha$ , relating to the relative amounts of labile DOM ( $\beta$ , often microbially produced or autochthonous/in-situ) to recalcitrant terrestrial carbon ( $\alpha$ , allochthonous) (Wilson and Xenopoulos, 2009).

#### 4.5 ATMOSPHERIC DEPOSITION FROM MEASURED DATA

The nitrogen budget from atmospheric deposition is summarised in Table 7. Total deposition at the sites varies from 12 – 34 kg N ha<sup>-1</sup> yr<sup>-1</sup>, with deposition lowest at Cors Bodeilio, and highest at Newbald Becksies water compound. At all sites, the majority of the atmospheric input comes from reduced N (i.e. ammonium in rain, and dry deposition of ammonia). The dry deposition of ammonia as a proportion of the total increases with the total amount of deposition. In other words, the dominant atmospheric source of N at high N sites comes from dry deposition of ammonia. Calculation methods for converting gaseous concentrations to a flux using the deposition velocity are shown in the Appendix. The average modelled deposition velocity for the UK (see Methods & Appendix) for moorland was 19.41 (+/- 2.46 standard deviation). This shows that the variation in the deposition velocity is relatively low compared with variation in the data between sites. Reference to the source attribution diagrams from APIS (Section 2) suggests that the proportion from agricultural sources is similar at all sites, and all are surrounded by agricultural land with some grazing. However, the magnitude of the agricultural contribution is not clear from the diagrams. Local conditions may reflect different type and strength of agricultural sources of ammonia. As discussed above, the contribution from NO<sub>x</sub> is low and broadly similar at all sites, so local power stations are unlikely to be a major contributor.

**Table 7 Atmospheric N deposition to the four sites, broken down by N form (kg N ha<sup>-1</sup> yr<sup>-1</sup>)**

	Dry deposition	Dry deposition	Wet deposition	Wet deposition	Total N flux
	NH <sub>3</sub> -N	NO <sub>x</sub> -N	NH <sub>4</sub> -N	NO <sub>x</sub> -N	
Wybunbury Moss	19.3	1.17	2.24	1.74	24.5
Newbald Becksies	19.1	1.22	4.63	2.8	27.8
Newbald water compound	25	1.36	4.63	2.8	33.8
Cors Bodeilio	6.7	0.45	2.89	2.44	12.5

#### 4.6 COMPARISON OF MODELLED APIS DATA TO SITE DATA

Measurements of gaseous concentrations at the site (Table 8) are compared to two national models. These models are the ‘CBED’ (Concentration Based Estimated Deposition) model produced on a 5 x 5 km<sup>2</sup> grid and incorporates wet and dry deposition data and the ‘FRAME’ (Fine Resolution Atmospheric Multi-pollutant Exchange) model, a transport model used to assess long term annual mean deposition of reduced and oxidised nitrogen and sulphur. The measured concentrations at the three GWDTEs in this study match the national models fairly closely for ammonia, although the measured concentrations at Newbald Becksies are a little higher than the national models. Gaseous concentrations of NO<sub>x</sub> are rather more variable, with concentrations at Cors Bodeilio and Wybunbury Moss considerably lower than the national models. This is a little surprising since NO<sub>x</sub> concentrations are relatively stable spatially across the UK. Understanding this spatial variability of NO<sub>x</sub> is outside of the scope of this report.

When scaled up to total N deposition (Table 9) using deposition velocities output from the FRAME model, the oxidised N values are similar to the models. The reduced N values (i.e. ammonia (dry) and ammonium (wet) calculated from the sites differ a little bit more. They are broadly comparable for Wybunbury and for Cors Bodeilio, but differ by over 50 % for Newbald Becksies. This suggests the importance of local monitoring to establish ammonia concentrations in order to accurately model deposition from reduced N compounds which comprise 2/3 of the atmospheric deposition load.

**Table 8 Comparison of NH<sub>3</sub> and NO<sub>x</sub> concentrations from CBED (Concentration Based Estimated Deposition), FRAME (Fine Resolution Atmospheric Multi-pollutant Exchange) model and measured on site concentrations.**

	NH <sub>3</sub> (µg/m <sup>3</sup> )			NO <sub>x</sub> (µg/m <sup>3</sup> )		
Site	Min	Max	Ave	Min	Max	Ave
<b>CEH CBED model concentrations</b>						
Wybunbury Moss	3.39	4.06	3.83	14	20.1	18.1
Newbald Becksies	2.21	2.21	2.21	13.8	13.8	13.8
Cors Bodeilio	1.3	1.52	1.4	6.25	6.42	6.33
<b>CEH FRAME model concentrations</b>						
Wybunbury Moss	3.38	3.57	3.55			
Newbald Becksies	2.44	2.44	2.44			
Cors Bodeilio	1.44	1.54	1.48			
<b>Measured concentrations</b>						
Wybunbury Moss			3.83			9.93
Newbald Becksies			3.79			10.4
Cors Bodeilio			1.34			3.87

**Table 9 Comparison of N deposition from CEH CBED deposition and measured deposition.**

	NH <sub>x</sub> (kg N/ha/yr)			NO <sub>x</sub> (kg N/ha/yr)			Total N (kg N/ha/yr)		
Site	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave
<b>CEH CBED deposition</b>									
Wybunbury Moss	22.4	25.2	24.5	3.6	3.8	3.6	26.2	28.8	28
Newbald Becksies	17.8	17.8	17.8	4.3	4.3	4.3	22.1	22.1	22.1
Cors Bodeilio	11.3	12.9	12	2.7	2.7	2.7	14	15.5	14.7
<b>Measured deposition</b>									
Wybunbury Moss			21.6			2.9			24.5
Newbald Becksies			23.8			4			27.8
Cors Bodeilio			9.6			2.9			12.5

#### 4.7 COMPARISON OF 'ALPHA' BADGE SAMPLERS WITH DIFFUSION TUBES

Comparison of the ALPHA badge samplers for NH<sub>3</sub> monitoring with the ET diffusion tubes revealed a number of issues (Table 10). Firstly, the field blank results for the diffusion tube data showed a high level of contamination during transport, storage and handling, even where site staff were particularly careful in handling the diffusion tubes, using protective gloves and following the protocols. Use of the field-blank in this analysis allowed us to correct for this additional contamination, and without this the recorded values would have been much greater. Therefore, we recommend a field blank should always be used.

Secondly, even with field-blank-correction, the diffusion tubes consistently recorded higher concentrations than the badge samplers, with concentrations 0.3 to 0.7 µg/m<sup>3</sup> higher. At Cors Bodeilio with low ammonia concentrations, this led to more than doubling of the ammonia concentration. At Wybunbury with higher ammonia concentrations, the differential was around 20 %. Similar findings have been shown in methodology comparison studies (e.g. Tang et al. 2001). Although these differences seem relatively small in magnitude, they make a large

difference to the calculated N deposition from ammonia, which comprises the bulk of the atmospheric deposition. This is important, because these values are all around the critical load, and could mean the difference between a site exceeding the critical load or not.

**Table 10 Comparison of ammonia sampling by diffusion tubes and ALPHA samplers**

Site	Exposure period		Ammonia concentration ( $\mu\text{g}/\text{m}^3$ )				Absolute difference	Percentage difference %
			ET diffusion tubes (Ave 3 tubes)	ET travel blank	ET travel-blank-corrected (Ave 3 tubes)	CEH ALPHA samplers (Ave 3 samplers)		
Cors Bodeilio	01/07/2016	01/08/2016	2.35	1.11	1.24	0.56	0.68	121.4
Newbald Becksies	01/07/2016	01/08/2016	3.37	1.1	2.27	1.93	0.34	17.6
Wybunbury	09/06/2016	13/07/2016	3.78	1.47	2.31	1.96	0.35	18
	13/07/2016	16/08/2016	5.41	1.81	3.6	2.82	0.78	27.8

Possible reasons for over-reading of atmospheric  $\text{NH}_3$  concentrations by the 3.5 cm membrane diffusion tubes are Contamination: sample preparation, transport and storage

The membrane diffusion tubes (not the ALPHA Samplers) used in this study are low sensitivity samplers with a low uptake rate. A small amount of contamination in the samples compared to laboratory blanks will give rise to a systematic over-estimation of  $\text{NH}_3$  concentrations due to the small loading to blank ratio (see Table 10 above).

Sources of contamination can result due to membrane inlet not capped / sealed off securely and sampling of  $\text{NH}_3$  could occur before and after exposure, resulting in contaminated samples and high and variable field blanks, influenced by length of time between sample preparation and exposure, length of time from site to laboratory /analysis and pollution climate of the site that samples are sent to (Tang et al. 2001). Adsorption of volatile ammonium salts on the membrane surface during exposure and subsequent volatilisation (changes in temperature and humidity from field to transport and storage) that is collected by the diffusion tube. Significantly better results at low concentrations were demonstrated where the membrane was replaced with a solid cap immediately after sampling (Sutton et al. 2001; Tang et al. 2001). The uptake rate used by ET is an old uptake rate derived in the 1980s that is higher than calibrated uptake rates reported by Tang et al. (2001) and more recently by Martin et al. (2018). The higher uptake rate applied by ET will result in a systematic over-estimation of  $\text{NH}_3$  concentrations.

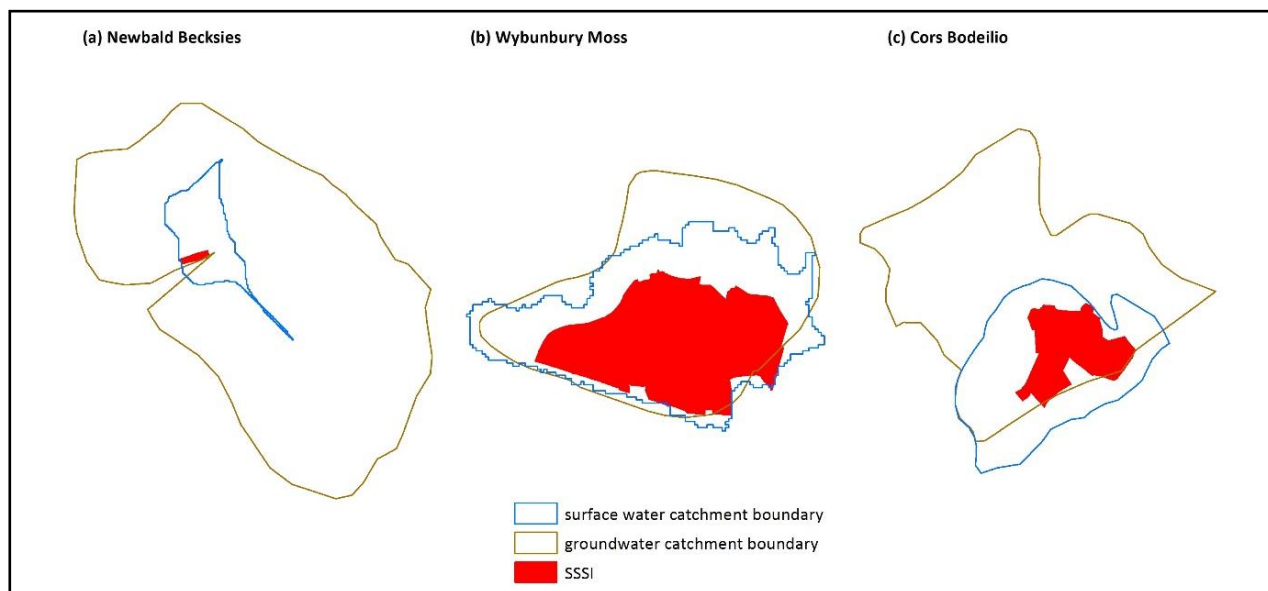
#### **4.8 NITROGEN DEPOSITION LOADING AND FLUX VIA SURFACE WATER AND GROUNDWATER CATCHMENTS**

Using the existing surface water and groundwater catchments (Figure 4-8) and the CBED nitrogen deposition data we were able to calculate which catchment received the highest total load and deposition flux. This is a useful desk based approach to estimate loadings at GWDTEs and can be applied using existing data available from EA and CEH.

The results of the analysis (Table 11; Table 12) show that Newbald Becksies, the largest catchment, receives the highest total catchment load (input) of atmospheric N deposition to the site catchments at  $19555 \text{ kg N year}^{-1}$ . Wybunbury Moss is the smallest catchment and has the smallest input of N to the site catchment ( $1836 \text{ kg N year}^{-1}$ ) but the highest deposition fluxes at ~

32 kg N ha<sup>-1</sup> year<sup>-1</sup>. Cors Bodeilio has the lowest deposition fluxes ~ 17 kg N ha<sup>-1</sup> year<sup>-1</sup>. However, this only indicates the total input load, not the amount likely to be leaving the catchment as leachate, or as surface runoff into streams or wetlands.

In the absence of detailed information on the proportion retained within the catchment, for the moment in order to assess the atmospheric nitrogen inputs to the study sites we recommend using the total values for the combined area of the surface water and groundwater catchments. This will give an upper bound for the atmospheric inputs. This is likely to be a considerable over-estimate and further work is required to estimate the proportion actually exported from this area to the wetland.



**Figure 4-8 Surface and groundwater catchment boundaries and location of SSSI within each study site**

**Table 11 Nitrogen deposition loads and fluxes to surface and groundwater catchments**

Site name	Catchment	Area (ha) <sup>##</sup>	Total atmospheric N deposition load to catchment (kg N year <sup>-1</sup> )	Atmospheric N deposition flux, area weighted by habitat types within catchment (kg N ha <sup>-1</sup> year <sup>-1</sup> )
Wybunbury Moss	Surface water	43.6	1436	32.9
	Ground water	54.3	1740	32.0
	Ground water only <sup>#</sup>	13.5	388	28.8
	Surface & ground water	57.6	1836	31.9
Newbald Becksies	Surface water	62.9	1378	21.9
	Ground water	862.4	19517	22.6
	Ground water only <sup>#</sup>	800.6	18163	22.7
	Surface & ground water	864.1	19555	22.6
Cors Bodeilio	Surface water	208.8	3474	16.6
	Ground water	457.7	7832	17.1
	Ground water only <sup>#</sup>	302.4	5227	17.3
	Surface & ground water	511.8	8706	17.0

<sup>#</sup>Groundwater catchment only, excluding any area overlapping with the surface water catchment.

<sup>##</sup>Based on overlaying the catchment boundaries on the CBED deposition re-gridded to 25m pixels to match the resolution of the CEH Land Cover Map 2000 (LCM2000) data (used to determine areas of woodland and non-woodland habitats within each catchment).



## 4.9 ATMOSPHERIC NITROGEN DEPOSITION EXCEEDANCE OF SITE RELEVANT CRITICAL LOADS

Using existing surface water and groundwater catchments (Figure 4-8), the CBED nitrogen deposition data and the EUNIS nitrogen critical load values we were able to calculate the exceedance of the critical load for each designated feature for each site (Section 2.14 and Table 12). The lowest exceedances are for the grassland and fen features which have higher critical loads ( $15 \text{ kg N ha}^{-1} \text{ year}^{-1}$ ); the exceedances are lower at Cors Bodeilio as this site also has the lowest deposition fluxes. The highest exceedance is for the bog habitat at Wybunbury Moss, as the critical load for this habitat is  $5 \text{ kg N ha}^{-1} \text{ year}^{-1}$ , and this site has the highest nitrogen deposition.

**Table 12 Critical loads, nitrogen deposition and critical load exceedance for designated feature habitats of SSSIs**

Site	Designated feature habitat(s)	EUNIS habitat class <sup>#</sup>	Nutrient nitrogen critical load <sup>##</sup> ( $\text{kg N ha}^{-1} \text{ year}^{-1}$ )	Area weighted mean nitrogen deposition to SSSI ( $\text{kg N ha}^{-1} \text{ year}^{-1}$ ) <sup>###</sup>	Exceedance of critical load ( $\text{kg N ha}^{-1} \text{ year}^{-1}$ )
Wybunbury Moss	Lowland bog	D1	5	27.9	22.9
Newbald Becksies	Moist & wet oligotrophic grassland	E3.51	15	21.8	6.8
	Valley mires, poor fens, transition mires	D2	10	21.8	11.8
	Rich fens	D4.1	15	21.8	6.8
Cors Bodeilio	Moist & wet oligotrophic grassland	E3.51	15	16.0	1.0
	Mountain rich fens	D4.2	15	16.0	1.0
	Valley mires, poor fens, transition mires	D2	10	16.0	6.0
	Rich fens	D4.1	15	16.0	1.0

<sup>#</sup> Closest corresponding habitat class of the European Nature Information System (Davies & Moss, 2002); nitrogen critical loads are assigned to EUNIS habitat classes (Bobbink & Hettelingh, 2011).

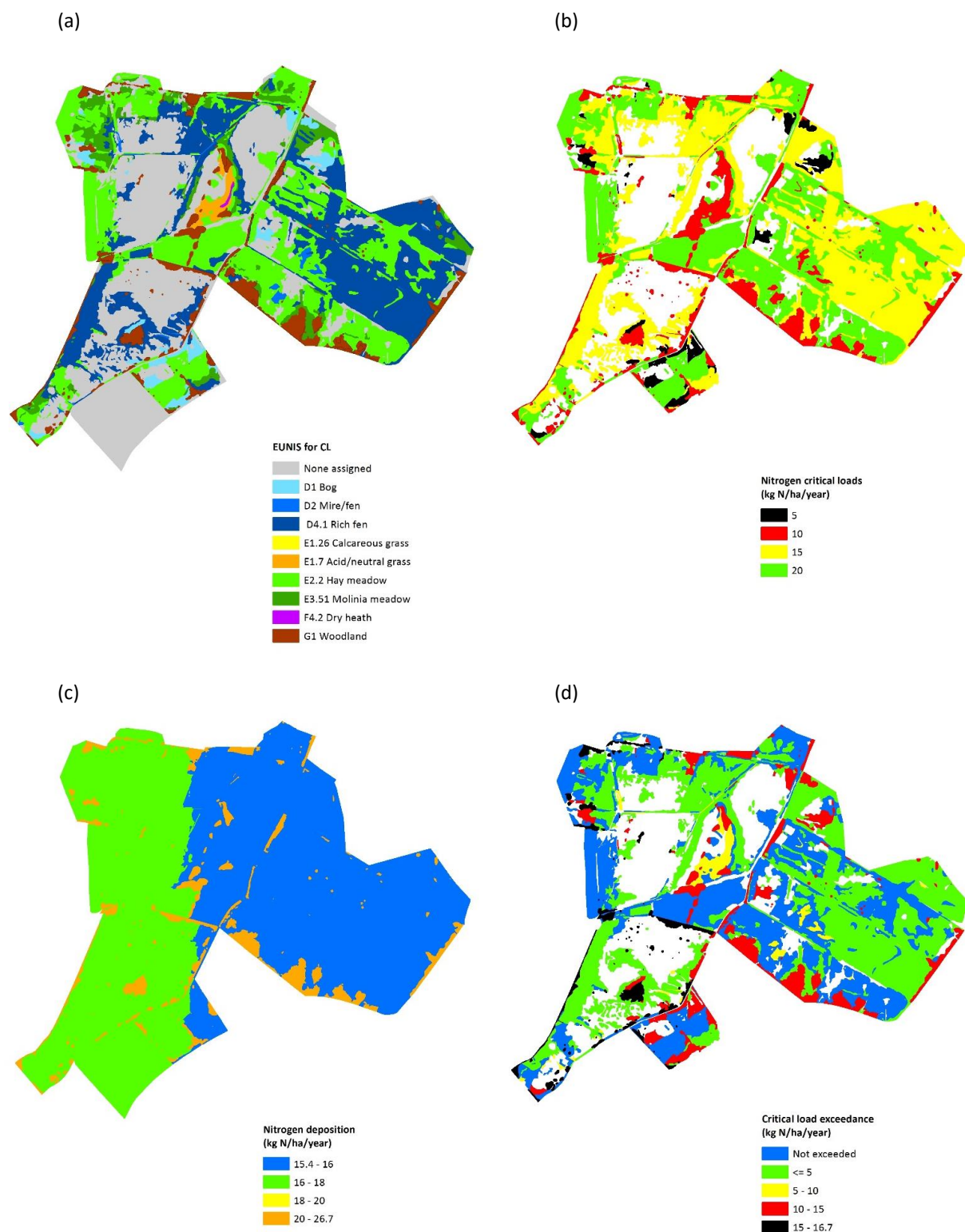
<sup>##</sup> Critical load values from the published ranges (Bobbink & Hettelingh, 2011) recommended by the UK Statutory Nature Conservation Bodies for casework and Article 17 reporting under the Habitats Directive.

<sup>###</sup> Deposition to moorland, area-weighted across whole of SSSI

#### **4.10 NITROGEN DEPOSITION CRITICAL LOAD EXCEEDANCES USING NVC MAPS**

We undertook a more detailed approach for one of the three study sites, Cors Bodeilio, using pre-existing NVC (National Vegetation Community) mapping and CBED deposition data. The aim was to look at how exceedance varied within a site, based on the critical loads for different habitats. Firstly, where it was possible each NVC community was linked to a EUNIS habitat class (Figure 4-9 a), with grey areas representing communities that could not be easily translated from NVC to EUNIS. The grey areas at Cors Bodeilio are mainly calcareous fen with cladium. Then the relevant nitrogen critical load was assigned to each polygon (Figure 4-9 b). Then the CBED 5 x 5 km nitrogen deposition data was applied to the habitats, the east west division (Figure 4-9 c) is due to Cors Bodeilio being situated across two of the 5 x 5 km squares. Finally the nitrogen critical load exceedance was calculated for each habitat polygon (Figure 4-9 d).

This spatially hi-resolution mapping exercise enables us to see the variation of nitrogen critical load exceedance within a single GWDTE. The highest exceedances are for the woodland habitats, partly because the deposition to woodland is greater than that to non-woodland habitats due to the higher dry deposition velocity to woodland. The areas with no exceedance of the critical load are the hay meadows (EUNIS class E2.2) which have a critical load of 20 kg N ha<sup>-1</sup> year<sup>-1</sup> which is higher than the moorland deposition flux to the SSSI (maximum 16.8 kg N ha<sup>-1</sup> year<sup>-1</sup>).



**Figure 4-9 Cors Bodeilio, detailed mapping of critical load exceedances (National Vegetation Classification polygons used with kind permission from Natural Resources Wales) Contains Ordnance Survey data licence number [100021290 EUL]**

(a) EUNIS class assigned to habitats where possible (b) Nitrogen critical loads assigned to habitat polygons by relating NVC classes to EUNIS classes where possible (c) CBED nitrogen deposition for 2011-13; moorland or woodland deposition value as appropriate, for single point within each habitat polygon (d) nitrogen critical load exceedance

#### **4.11 NITRATE SOURCE APPORTIONMENT MODELLING USING ‘FARMSCOPER’**

The FarmScoper modelling tool was used to estimate nitrate leaching at Wybunbury Moss and Newbald Becksies. Non-agricultural sources of nitrate and agricultural point sources have been estimated using results of earlier work by Amec (2010). The input data and results, are summarised below and are based entirely upon an analysis undertaken by Wood Plc, formerly Amec Foster Wheeler, for the Environment Agency (Environment Agency, 2018 a, b & c).

##### **4.11.1 Wybunbury Moss**

FarmScoper was used to look at the area to the north of Wybunbury Moss, as this is where the hydrogeological conceptual model suggests there is most significant groundwater flow towards the moss. Input data for the FarmScoper modelling tool, combined with non-agricultural source data (Amec, 2010) is summarised in Table 13. Observed nitrate concentrations collated from Environment Agency and Natural England groundwater analysis (2010-2016) show that groundwater nitrate concentrations can be variable within the sand and gravel aquifer to the north of the wetland, with average concentrations between 1.14 mg/l N to 41.44 mg/l N (Environment Agency, 2018b). However the observed nitrate concentrations are significantly lower within the adjoining lagg fen (0.1 mg/l N) (Environment Agency, 2018b) and are often close to or below the limit of detection (<0.196 mg/l N) within and below the main peat raft e.g. sample point ‘PTC’ which monitors groundwater below the peat raft (see Appendix for data).

FarmScoper modelling suggests that N loadings are dominated by leaching from the adjacent agricultural land, which would produce average concentrations of nitrate between 5.0 and 10.3 mg/l N (Table 14 C, leaching scenario 1 – 2 respectively). The modelling does not suggest that point sources are significant. The model suggests that different land uses e.g. maize, wheat or grassland produce a variability in predicted nitrate leaching concentrations with maize producing the highest predicted nitrate leaching values (Environment Agency, 2018b).

The results were compared to the observed nitrate leaching values. The modelling data broadly matches the variability seen in the observed nitrate concentration data, however the modelled nitrate concentrations are not as high as the observed nitrate concentrations. Considerable uncertainty in the model predictions may be the result of various factors, including; under estimation of fertiliser application and soil nitrogen supply, failure to account for biogeochemical conversions of ammonium to nitrate and the possibility that the observed data used in the analysis is not representative of the longer term trends. Furthermore land use was estimated based on field observations and maps and thus land use was not confirmed for each field. It is also possible that the nitrate concentrations in groundwater represent past land use practices and include periods of higher rates of fertiliser application. CFC & SF<sub>6</sub> dating indicates a range of recharge dates for groundwater in the sand and gravel aquifer between 1959 to the present day. The effect of the nitrate time lag should be considered and where groundwater is young it suggests that land management changes could have rapid results in reducing nitrate.

FarmScoper allows mitigation scenarios to be applied to the modelled area. In this example the field to the north is considered to be the greatest source of groundwater nitrate, contributing over half of the leachable nitrate in both modelled scenarios (Table 14). Suggested mitigation measures include replacing the maize with lower nitrate input activities including, wheat, pasture, grassland or woodland. The various mitigation measures all produce reductions in modelled nitrate concentrations, however none of the proposed actions produce a reduction in nitrate great enough for groundwater nitrate concentrations to reach the 2 mg/l threshold value proposed for peatbogs at any altitude (UKTAG, 2012b). Threshold values are designed to identify GWDTE where damage could be caused and they should not be confused with nitrate ‘targets’ which they are not.

A) Catchment data and assumptions	
Variable	Description
Soil type	Sandy, free draining
Annual rainfall	695 mm/yr (after Ingram and Seymour, 2009)
Summer rainfall	350 mm (half of the annual total rainfall)
RB209 grass growth class	Poor
Area of pasture fields (ha)	14
Area of wheat field (ha)	1.6
Area of maize field (ha)	4.3
Farmscoper Rainfall Band	700 – 900 mm rainfall (Note 1)
Farmscoper soil type	Free draining

B) Land management Scenarios			
Land Use Scenario	Nitrogen Fertiliser Rate	Stocking Rate (LU/ha)	Comments
Maize 1	150 kg/ha inorganic + managed manure from 14 cattle.	N/A	Inorganic fertiliser rate is the RB209 rate for a SNS index of 0. No allowance is made for the nutrient content of the applied manure, which is calculated as 93 kg/ha (total N).
Maize 2	100 kg/ha inorganic No manure.	N/A	Fertiliser rate is the RB209 rate for a SNS index of 1
Wheat 1	160 kg/ha inorganic	N/A	Fertiliser rate is the RB209 rate for a SNS index of 0 on light sandy soil.
Wheat 2	130 kg/ha inorganic	N/A	The RB209 fertiliser rate for a SNS index of 1.
Pasture 1	Zero inorganic + managed manure	0.6 LU/ha (14 cattle in total)	Manure assumed spread to permanent pasture.
Pasture 2	Zero inorganic.	0.3 LU/ha (7 cattle in total)	Manure assumed spread elsewhere.

C) Groundwater catchment data (non agricultural and agricultural point sources)		
Parameter	Value	Comment
Sewered Population	46	Approx. 20 dwellings, average 2.3 people per household.
Population served by septic tanks / Package Treatment Plants	0	
Area of gardens	1 ha	Assumed associated with farms and dwellings on Stock Lane.
Area of manure heaps	0.1 ha	
Area generating farmyard runoff	0.5 ha	Paddocks and yards
Area of paved and road surfaces	0.5 ha	

**Table 13 Wybunbury Moss: FarmScoper Input (EA, 2018b)**

**a) catchment data and assumptions b) land management scenarios and c) groundwater catchment data (EA, 2018b).**

A) Results of FarmScoper Modelling					
Land Use / Scenario No.	Area (ha)	Drainage (mm/yr) (1)	Nitrate-N Load (kg-N/ha/yr)	Nitrate-N concentration (mg-N/l)	Nitrate-N Load (kg N/yr)
Maize 1	4.3	341	93.4	27.4	401.6
Maize 2	4.3	341	42.9	12.6	184.4
Wheat 1	1.6	374	35.9	9.6	57.5
Wheat 2	1.6	374	33.6	9.0	53.7
Pasture 1	14.0	329	15.2	4.6	212.7
Pasture 2	14.0	329	5.7	1.7	79.1

B) Estimated loading from point Sources and non agricultural sources		
	N Load (kg N/yr)	Comment
Sewer leakage	3.5	
Mains leakage	7.2	
Manure heaps	1.9	Assumed leachate quality 10mg-N/l, 100mm of drainage per year.
Roads	0.2	
Urban area	0.1	
<b>TOTAL</b>	<b>12.9</b>	

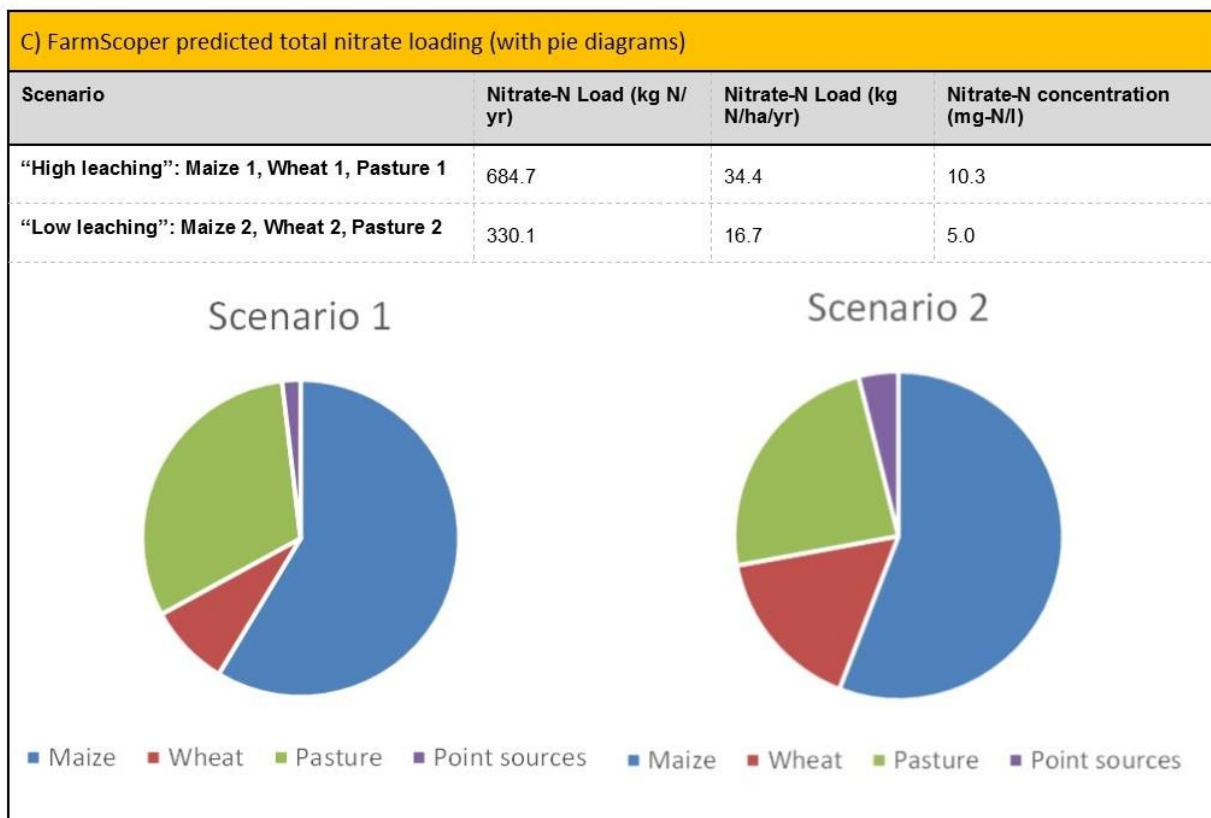


Table 14 Wybunbury Moss: FarmScoper Results (EA, 2018b)



**Table 15 Wybunbury Moss: FarmScoper Mitigation Measures (EA, 2018b)**

Mitigation Scenario (maize field)	Nitrate-N concentration (mg-N/l) (maize field)	Nitrate-N concentration (mg-N/l) (whole catchment)
Establish cover crop in autumn	17.3	5.8
Change from maize to winter wheat	9.0	4.1
Change from maize to cut grass (silage)	12.0	4.6
Change from maize to extensive grass	1.7	2.4
Change from maize to woodland (reversion)	2.7	2.6

#### 4.11.2 Newbald Becksies

FarmScoper was used to assess nitrate leaching from the groundwater catchment of Newbald Becksies, with non-agricultural sources of nitrate and agricultural point sources estimated using results of earlier work by Amec (2010). Unlike Wybunbury Moss, Newbald Becksies has the benefit of being both within the wider area covered by the Environment Agency ‘Yorkshire Chalk’ groundwater model and also having had its own MODFLOW model produced in fulfilment of an MSc project (Wilkinson, 2009). The groundwater catchments were reviewed and an output from the EA groundwater model was chosen (Environment Agency, 2018a). The groundwater catchment was split into four areas; north east, north west, south east and south west. Input data for the FarmScoper modelling tool is summarised in (Table 16). Observed nitrate concentrations were measured from the boreholes and springs at the wetland. Environment Agency water chemistry data from two periods (2009-2010 and 2015-2016) were collated and comparison suggests that nitrate concentrations have remained relatively constant (see Figure 4-2). Springs and boreholes are sampled at the wetland, nitrate concentrations are lowest in the ‘Spring 1’ in the east of the site (12.3 mg/l N to 15.0 mg/l N) and highest in ‘Borehole West’ (17.5 -19.8 mg/l N).

Potential sources of nitrate in the groundwater catchment include; leaching from agricultural soils, atmospheric deposition directly to the site, mineralisation on site, manure heaps / horse paddocks, septic tanks, sewer leakage and mains water leakage (Environment Agency, 2018a).

The outputs from FarmScoper have been divided into four areas; north west, north east, south east and south west. The predicted nitrate concentrations are tabulated (Table 17 a) and predicts that arable land use, namely Oil Seed Rape and Vining Peas would result in the greatest groundwater nitrate concentrations. Point sources such as sewer leakage and septic tanks (Table 17 b) are not predicted to be significant contributors to groundwater nitrate concentrations.

Comparison between the modelled predictions (15-17 mg /l N) and the observed results (12.3 - 19.8 mg/l N) are good, and there is less uncertainty than in the previous Wybunbury Moss example. The results are presented as pie charts, for sub-catchments of the groundwater catchment (Figure 4-10) and show that the majority of nitrate is leached from arable land, which based on aerial photographic assessment is assumed to be used for oilseed rape and vining peas (Environment Agency, 2018a).

FarmScoper allows mitigation scenarios to be applied to the modelled area, for example the best combination of measures to reduce nitrate within a groundwater catchment. Suggestions include undersown spring cereals, manufactured fertiliser placement technologies, integrated fertiliser and nutrient supply, fertiliser spreader calibration and use of plants with improved nitrogen use efficiency. However, even if all of these options were combined, the FarmScoper model predicts a reduction of groundwater nitrate to 13.7 mg/l N, still far above the 2 mg/l threshold value (UKTAG, 2012b). Threshold values are designed to identify GWDTE where damage could be caused and they should not be confused with nitrate ‘targets’ which they are not.

There are many examples of practical solutions to the reduction of nitrate in catchments, including Yorkshire Water’s proposed catchment measures within the ‘safeguard zone’ for Newbald public water supply (near Newbald Becksies wetland), which will help to reduce nitrate loading by implementing land management changes within a catchment. However the threshold values for drinking water of 11.3 mg/l N are higher than the proposed Threshold Value of 2 mg/l N.

A) Catchment data and assumptions					
Variable	Total	North East	North West	South East	South West
Soil type	Loamy shallow free draining				
Annual rainfall (2004-2016)	600mm/yr				
Summer rainfall	330 mm				
Farmscoper Rainfall Band	600-700mm				
RB209 grass growth class	Average				
Area of arable fields (ha)	886.7	146.8	214.4	234.5	291.1
Area of grazed grass (ha)	101.5	1.7	8.2	60.8	30.8
Area of rough grazing (ha)	14.2	0	0	14.2	0
Area of woodland (ha)	48.4	0	2.5	12.4	33.5
Urban area (ha)	8	0	8	0	0

B) Land management Scenarios			
Land Use Scenario	Nitrogen Fertiliser Rate	Stocking Rate (LU/ha)	Comments
Winter Oil seed rape	220 kg/ha inorganic	N/A	The RB209 fertiliser rate for a SNS index of 1
Winter wheat	240 kg/ha inorganic	N/A	The RB209 fertiliser rate for a SNS index of 1
Spring Barley (malting)	120 kg/ha inorganic	N/A	The RB209 fertiliser rate for a SNS index of 1
Vining peas	0 kg/ha	N/A	The RB209 fertiliser rate for a SNS index of 1
Grazed Grass	170 kg/ha inorganic	1.5 LU/ha (9 ewes plus lambs per ha)	Assumed no manure spread to grazed grass
Rough Grazing (as defined by FarmScoper)	Zero inorganic	0. LU/ha	Assumed no manure spread to rough grazing
Woodland (as defined by FarmScoper)	Zero inorganic.	NA	

C) Groundwater catchment data (non agricultural and agricultural point sources)					
Parameter	North West	North East	South West	South East	Comment
Sewered Population	115	0	0	0	Approx. 50 dwellings, average 2.3 people per household
Population served by septic tanks / Package Treatment Plants	3	7	9	5	Approx. 10 dwellings, average 2.3 people per household
Area of gardens (ha)	1	0	0	0	Assumed 50 hours in 8 ha urban area
Area of manure heaps (ha)	0.1	0	0	0	
Area of paved road surfaces (ha)	0.4	0.4	0.9	0.9	Approx. 6.4 km of road estimated at 4 m wide

**Table 16 Newbald Becksies: FarmScoper Input (EA, 2018c)**

<b>A) Results of FarmScoper Modelling: nitrate leaching in each sub-catchment</b>					
	North East	North West	South East	South West	Total Catchment
Area (ha)	148.5	233.1	321.9	355.4	1058.8
Total nitrate-N loading (kg-N/yr)	6001	8852.4	10530.6	123322.1	37706.1
Total nitrate-N loading (kg-N/ha/yr)	40.4	39.3	32.7	34.7	35.9
Total drainage (mm/yr)	235.7	231.7	217.3	209.3	220.3
Average concentration (mg/N/l)	17.1	17.0	15.1	16.6	16.3

<b>B) Estimated loading from point Sources and non agricultural sources (N Load (kg N/yr)</b>				
	North East	North West	South East	South West
<b>Sewer leakage</b>	0	8.7	0	0
<b>Septic tank discharges</b>	11.5	4.9	8.2	14.8
<b>Mains leakage</b>	1.1	18.5	0.8	1.4
<b>Leaching from gardens</b>	0	1	0	0
<b>Leaching from manure heaps</b>	0.01	0.01	0.06	0.06
<b>TOTAL</b>	<b>12.61</b>	<b>38.11</b>	<b>9.06</b>	<b>16.26</b>

<b>C) Results of FarmScoper: predictions of nitrate leaching from each land use scenario</b>			
	Nitrate Loss (kg-N/ha)	Soil Drainage (mm)	Nitrate Concentration (mg N/l)
<b>Winter Oil Seed Rape</b>	15.28	181.23	8.43
<b>Winter wheat</b>	50.61	249.03	20.32
<b>Spring barley (malting)</b>	31.75	249.03	12.75
<b>Vining Peas</b>	27.94	223.68	12.49
<b>Grazed Grass</b>	52.53	223.68	23.49
<b>Rough Grazing (defined by FarmScoper)</b>	0.04	-	-
<b>Woodland (defined by FarmScoper)</b>	4.01	247.76	1.62

**Table 17 Newbald Becksies: FarmScoper Results (EA, 2018c)**

D) FarmScoper predicted total nitrate loading (with pie diagrams)

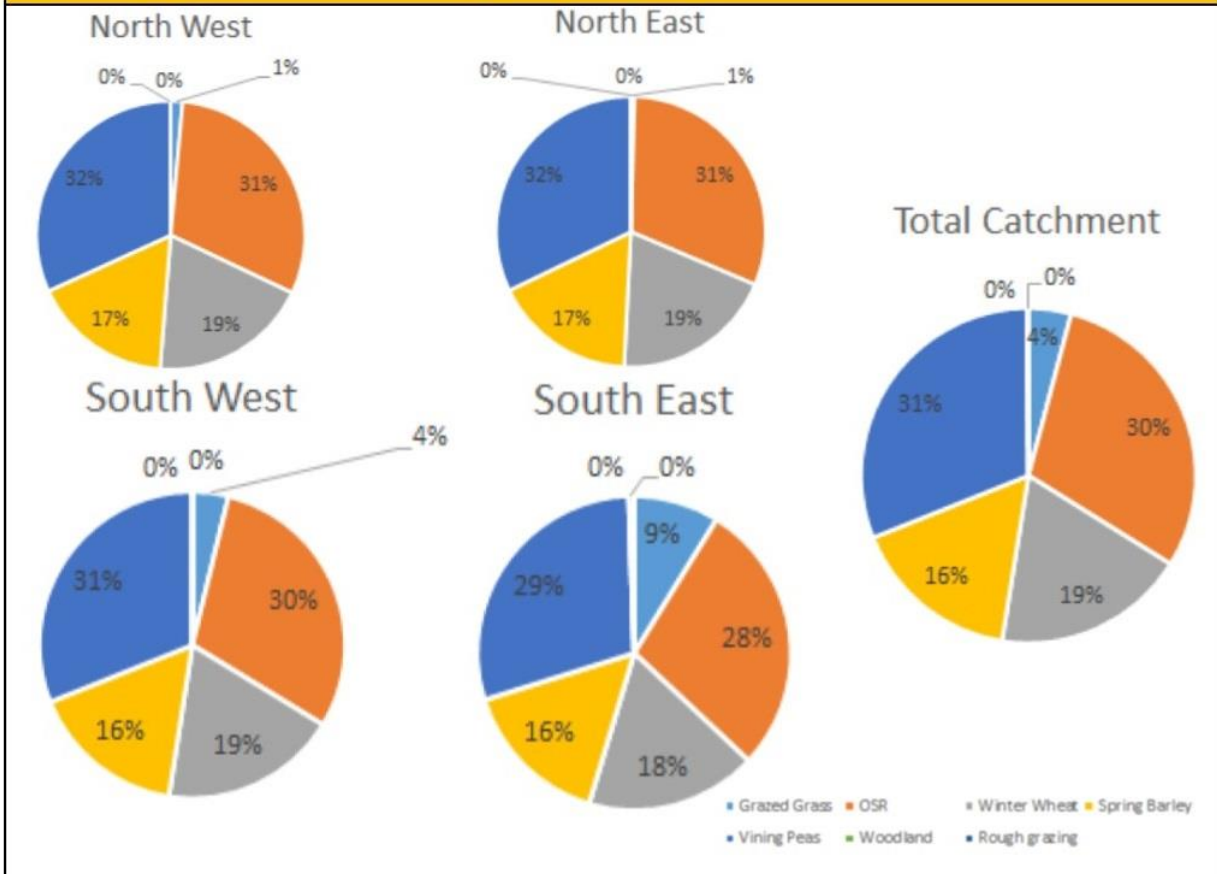


Figure 4-10 Newbald Becksies: FarmScoper Results Pie Charts (EA, 2018c)



## 4.12 SUMMARY OF RESULTS

Each GWDTE has now been subject to assessments under the Habitats Directive and the Water Framework Directive, analysis of water chemistry, isotopes and age, modelled data for atmospheric deposition has been compared to measured on site data and nitrate loading tools applied to two of the study sites. The key results and data are collated in a single table (Table 18) for easy reference. For full analysis see previous chapters and or appendices.

**Table 18 Summary of key data from study**

			Wybunbury Moss	Newbald Becksies	Cors Bodelio
Habitats Directive condition			Unfavourable	Unfavourable	Unfavourable
Water Framework Directive Chemical and Quantitative Classification (2 <sup>nd</sup> Cycle, 2013)			Poor – at risk	Poor – at risk	Poor – at risk
Groundwater nitrate-N concentrations (data from wetland & GW-SE catchment) N mg/l	Maximum Minimum Mean		39.3 0.1 14.8	19.8 12.3 16.4	12.3 <0.0197 2.2
Groundwater Threshold Value (N mg/l)			2	2	2
Groundwater Threshold Value exceeded ? (N mg/l)			Yes	Yes	Yes
EUNIS habitat class (Bobbink & Hettelingh, 2011)			D1	E3.51;D2; D4.1	E3.51;D4.2; D.2; D4.1
Site relevant critical Load Nutrient nitrogen (kg N/ha/yr) (Bobbink & Hettelingh, 2011)			5	10-15	10-15
Area weighted mean nitrogen deposition to SSSI (kg N/ha/yr)			27.9	21.8	16.0
Critical load exceeded ?			Yes	Yes	Yes
Exceedance of critical load (kg N/ha/yr)			22.9	6.8-11.8	1.0-6.0
Atmospheric Deposition (average kg N/ha/yr)	CBED model	NH <sub>3</sub>	24.5	17.8	12.0
		NOx	3.6	4.3	2.7
		Total N	28.0	22.1	14.7
	Measured data	NH <sub>3</sub>	8.7	11.0	5.1
		NOx	2.8	3.9	2.9
		Total N	11.5	14.9	8.0
Flux to wetland area weighted by habitat types in catchment (kg N/ha/yr)	SW	32.9	21.9	16.6	
	GW	32.0	22.6	17.1	
	SW&GW	31.9	22.6	17.0	
FarmScoper modeled catchment loading (kg/ N/ha/yr)			16.7 -34.4	35.9	na
FarmScoper predicted groundwater N mg/l Section 4.11			5 - 10.3	15.1-17.1	na
Is FarmScoper comparable to measured GW Nitrate?			Under estimate	Good	na
FarmScoper proposed mitigation (crop cover, crop change etc)			section 4.12.1	section 4.12.1	na
Can proposed mitigation reduce N to < threshold value			No	No	na

## 5. Discussion

### 5.1 INVESTIGATION PROCESS

We have arranged the process for investigating nutrient impacts at GWDTEs into a flowchart to help with decision-making (Figure 5-1).

- **Step 1:** Decide if an investigation into nutrient impacts at a GWDTE is required. Consult the existing evidence including assessments made during the Habitats Directive Review of Consents, and status assessments from the first two cycles of River Basin Planning for the Water Framework Directive. If the site is deemed in unfavorable condition then proceed to the following steps, however if the site is in favourable condition there should be no need to investigate.
- **Step 2:** Does HD assessment show the site to be unfavorable ? Talk to site managers, local area hydrogeologists, and air quality experts. Steps 1 and 2 can occur simultaneously.
- **Step 3:** Does a robust conceptual model exist for the GWDTE? If the source-pathway-receptor (SPR) relationships can be identified then this may be enough to identify the main nutrient pathways and to implement effective measures to reduce nutrient pressures. If however the conceptual understanding needs improving then speak to your area groundwater specialists and site managers about what would be required.
- **Step 4:** Identify atmospheric deposition and critical loads using freely available open access modelled data ([www.apis.ac.uk](http://www.apis.ac.uk)) have the critical loads been exceeded ? If ‘yes’ considered if effective measures could be applied to reduce the loading, speak with air quality specialists. If critical loads have not been exceeded, we must consider other pathways for nutrients working with groundwater specialists and site managers.
- **Step 5:** Use catchment modelling approaches to calculate loadings where possible. Consider which nitrate leaching tool is most appropriate e.g. FarmScoper, EA nitrate leaching tool and if sufficient data exists to be able to successfully run these tools.
- **Step 6:** If new chemical data is required (in addition to that collected as part of HD and WFD monitoring) then consider the most cost-effective approach to site specific investigations. Talk to your groundwater team. Plan the sample program and consider what duration, frequency, and type of analysis would contribute most to improving your conceptual understanding of the GWDTE.
- **Step 7:** Following the steps above could provide evidence to help define effective measures aimed at reducing nutrient pressure and loading to the GWDTE thus improving site condition status (Habitats Directive) and groundwater status (WFD).

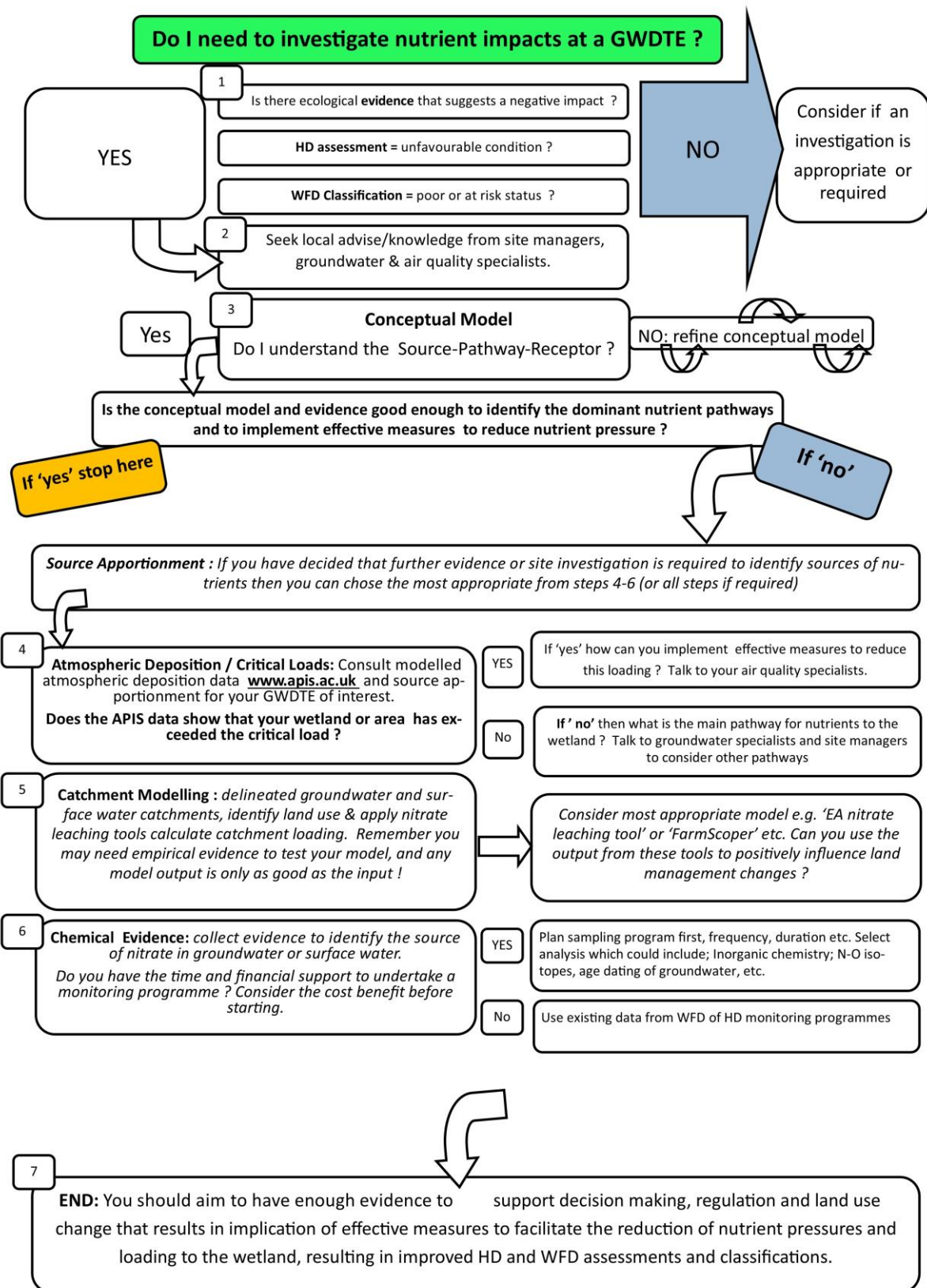


Figure 5-1 Flow chart to aid decision making before wetland investigation

## **5.2 LONG-TERM MONITORING TRENDS**

Existing long term monitoring, often undertaken for WFD or HD, can be extremely useful to provide confidence of persistent pressures, e.g. nitrate concentrations. When chemical monitoring has been undertaken over several years it can provide evidence of nitrate concentrations but also delineate any important trends (e.g. decreasing, increasing or staying about the same) further supporting the need, or not, for further investigation.

## **5.3 NITROGEN AND OXYGEN ISOTOPES**

Nitrogen and oxygen isotope analysis can be used in conjunction with other analysis to better understand the sources of nitrate at GWDTEs. The isotope method is affordable ranging from £30 +VAT per sample (price correct as of 2016). However isotope data alone should not be used to identify sources of nitrate, this is because a range of processes including mixing and dilution could give spurious results. It is strongly recommended that a good conceptual model and spatial and temporal inorganic water chemistry data are used to support interpretation of isotope data. Isotope data could also be used to support nitrate leaching models including 'FarmScoper' and could also be applied to other studies where it is useful to determine the source of nitrate in groundwater e.g. Source Protection Zones or Drinking Water Protected Areas.

## **5.4 NITRATE ANALYSIS AND CFC & SF<sub>6</sub> DATING**

CFC & SF<sub>6</sub> dating techniques are useful to indicate a range of recharge dates in modern groundwater systems. Coupled with other data, e.g. nitrate concentration time series data, they can help improve the conceptual model. However the nitrate time lag effect must be considered as high nitrate concentrations may not relate to present day land use. Future studies could incorporate modelling of future nitrate trends into analysis.

## **5.5 ATMOSPHERIC DEPOSITION**

Before embarking upon new site specific monitoring programs the following advantages and disadvantages of using the published APIS or CBED data should be considered. CBED concentration and deposition data can be freely looked up on [www.APIS.ac.uk](http://www.APIS.ac.uk) using either grid reference or name of designated site.

Desk based assessments can save time and money avoiding the need for lengthy and expensive site investigations. CBED data can be interrogated for any designated site – or grid reference, free of charge on [www.apis.ac.uk](http://www.apis.ac.uk). The data is applied across the UK allowing comparison of sites against a single modelled dataset. Despite the advantages of such a resource some of the limitations of the model should be considered

APIS/CBED is modelled on a 5x5 km grid and averaged over a 3 year period, however in reality concentrations will vary within the modelled grid and also over time. For example the data will include emissions from established local sources but may not include all "hotspots" of high deposition as these can be obscured in the modelled grid.

If the APIS data suggest the critical load is greatly exceeded, then this is likely the case. If APIS suggests the deposition is close to the critical load (either above or below), then it may be worth conducting site-specific measurements to clarify the inputs from atmospheric deposition.

There will be uncertainties associated with measurements, rainfall data, modelling of dry deposition, equipment used to take measurements, potential local contamination, limits of detection in analysis. There are other short and long range models available and examples are described on the APIS website <http://www.apis.ac.uk/air-pollution-modelling>.

## 5.6 DIFFUSION TUBES

Accurate measurement of  $\text{NH}_3$  concentrations requires high quality and robust sampling procedures. This is important because ammonia constitutes a substantial part of the atmospheric N deposition budget. While the ALPHA samplers cost more than standard diffusion tubes, their improved accuracy is critical to getting robust measurements of ammonia at a site. Ammonia concentrations are very spatially variable, and are governed to a large extent by many local sources. This means that national models of ammonia concentrations carry a high uncertainty and site measurements are recommended to get a more accurate picture at a site level.

## 5.7 CRITICAL LOADS

The nitrogen critical load values applied to the habitat features in this study are those recommended by the APIS Steering Group for use in air pollution impact assessments (<http://www.apis.ac.uk/indicative-critical-load-values>) and are based on the internationally (Bobbink & Hettelingh, 2011) and nationally (Hall et al. 2015) agreed critical loads. The critical loads for each habitat are expressed as a range, with users selecting a value within that range for the calculation of critical load exceedance; both the UK report (Hall et al. 2015) and the APIS website provide recommended values within these ranges for this purpose.

The national CBED 5x5 km nitrogen deposition data (RoTAP, 2012) are extensively used in Defra-funded research for assessing the potential impacts of nitrogen on sensitive habitats (e.g. Hall et al. 2015), and on the APIS website ([www.apis.ac.uk](http://www.apis.ac.uk)). CBED provides maps of (a) wet deposition based on ion concentrations in precipitation from the UK Eutrophying and Acidifying Pollutants (UKEAP) network combined with UK Met Office annual precipitation; (b) dry deposition derived from gas and particulate concentration maps combined with spatially distributed estimates of vegetation-specific deposition velocities. The data used in this study are the sum of wet (including cloud) plus dry deposition, averaged over a three-year period to smooth out inter-annual variations in deposition.

However, uncertainties exist in both critical loads and deposition and the following points should be noted:

- The critical load ranges are published with an associated “reliability score” based on an assessment of the amount of evidence underpinning them: reliable, quite reliable, expert judgement (Bobbink & Hettelingh, 2011).
- The critical load values recommended for air pollution impact assessments of habitat features within designated sites tend to be set at the lower end of the published ranges (<http://www.apis.ac.uk/indicative-critical-load-values>). In national scale assessments a different value within the critical load range may be used, based on UK evidence of air pollution impacts (Hall et al. 2015).
- Critical loads are not available for all habitat types (Bobbink & Hettelingh, 2011); if appropriate it may be possible to apply values for a different habitat that is known, or likely, to have a similar response to nitrogen. APIS provides this information on a site-specific basis. Habitat-level proxy critical loads have been assessed in a study for JNCC and are available online (Jones et al. 2016).
- The CBED data assume that deposition is constant across each 5x5 km grid square. The data will include emissions from established local sources, but may not include all “hot spots” of high deposition observed in some higher resolution data or model outputs.
- There can be uncertainties associated in the measurements of concentrations, rainfall, the modelling of dry deposition (including deposition velocities). This can apply to site-based measurements as well as CBED or data from other atmospheric dispersion models; the latter may also include uncertainties in the emissions data.



- For site-based studies it may be preferable to use local-scale atmospheric dispersion models (e.g. <http://www.apis.ac.uk/air-pollution-modelling>) for source apportionment, though there will still be uncertainties associated with these. Site based studies may well require on-site measurements of ammonia concentrations, ideally using BADGE samplers (see critique of the ammonia monitoring results in section 4 and section 5.6 above).
- If comparing CBED or modelled deposition with site-based measurements it is important to check that the data are comparable and measuring the same components.

Work carried out by Jones et al. (2016) for JNCC developed a decision framework to provide a means of attributing atmospheric nitrogen deposition as a threat to, or cause of, unfavourable habitat condition on protected sites. This study incorporated some simple estimates of uncertainties in both nitrogen critical loads and deposition in the assessment process; this provided an “exceedance score” rather than a single critical load and an exceedance value. It recommended combining this “national/theoretical” evidence with additional site-based evidence to give an overall assessment.

## **5.8 MODELLING TOOLS**

When using any predictive models (e.g. FarmScoper) it is important to remember that the results they produce are based upon the quality of the input data. Considerable uncertainty in model predictions may be the result of various factors, including; under estimation of fertiliser application and soil nitrogen supply, failure to account for biogeochemical conversions of ammonium to nitrate and the possibility that the observed data used in the analysis is not representative of the longer term trends. Further uncertainty can be added if land use is estimated from aerial photographs rather than from field records.

## **5.9 COMBINED ASSESSMENT OF ATMOSPHERIC AND TERRESTRIAL INPUTS**

This is a complex issue and not easily done within the scope of this study. Additional data is needed on the relative proportion of atmospheric inputs that is leached from semi-natural habitats and from arable or improved pasture areas where other anthropogenic inputs are much higher – the proportion of atmospheric deposition that is leached will differ across these habitat types due to N saturation in land uses receiving other inputs. As a very rough calculation, based on the FarmScoper outputs presented in this report, leaching rates for arable land vary from approximately 20 – 40 % of inputs, with the exception of oil seed rape where leaching rates are only 7%. Leaching rates from pasture areas vary from 15-30%. Applying a maximum observed leaching rate to atmospheric inputs suggests that for these agricultural areas, they will be roughly 20 % of the magnitude of the agricultural leaching rates, on the agricultural land. On semi-natural habitats, the leaching rates are likely to be much lower, FarmScoper estimates for Newbald Beckies on unimproved grassland suggests that leaching fluxes are < 1 kg N/ha/yr.

Based on these very rough calculations, and pending more robust estimates, we suggest that atmospheric inputs contribute a maximum of 20 % of the nitrogen leaching which derives from inputs to agricultural land.

## 5.10 BETTER REGULATORY PROTECTION OF WETLANDS (GWDTEs)

Once damage has occurred to a GWDTE restoration can be difficult and costly. **It is far better to offer protection to a wetland than it is to restore it once damage has occurred.** Protection can be offered by the range of wildlife designations but also from effective measures within groundwater bodies linked to GWDTEs.

The current legislative framework for protecting GWDTEs can appear complex. There isn't a single 'off the shelf' directive that deals with GWDTEs. Multiple pathways and receptors mean that often the regulator must engage with the Habitats Directive (species) and the Water Framework Directive (surface water and groundwater) simultaneously.

The methodology presented in the report could be applied to the Natura 2000 sites in England with pending **Diffuse Water Pollution Plans (DWPP)**. The DWPP are a joint initiative between the Environment Agency and Natural England. The DWPP could seek land owners willing to enter into voluntary agreements (Natural Environment and Rural Communities Act 2006) or regulatory powers could be used to implement change. The following regulatory mechanisms can be considered to support land use changes around Natura 2000 sites;

- Special Nature Conservation Orders (Habitats Regulations 2017),
- Water Protection Zones (Water Resources Act 1991 S93) or
- Use of Environmental Permitting Regulations (England & Wales 2010).
- GWDTEs may also be protected if they are included within Safe Guard Zones and Source Protection Zones.

## 6. Conclusions and Recommendations

Groundwater dependent terrestrial ecosystems (GWDTEs) face multiple nutrient pressures from surface water, groundwater and atmospheric pollutant pathways. This study, based on investigations at three GWDTEs attempts to apportion nitrate at wetlands to various sources and pathways and provide transferable methods and tools for investigation at GWDTEs.

Existing Water Framework Directive classification test and Habitats Directive assessments were used to highlight sites deemed to be under pressure. Surface water and groundwater catchments, baseline chemical data, geological and habitats mapping was used to develop conceptual models sufficient enough to characterise the main source pathway and receptors for the nutrients of concern.

Identifying and mitigating pressures can be best achieved by working as part of multidisciplinary team, using evidence to implement the most suitable programme of measures. Options to implicate effective measures within the current regulatory structure include; programmes of measures for the Water Framework Directive, Diffuse Water Pollution Plans, Source Protection Zones, Safeguard Zones or via the permitting and licensing regimes. Engaging with local communities and landowners to get the best result from land management schemes and agreements.

Public bodies are under constant funding pressures and open access web tools such as the ‘Air Pollution Information System’ ([www.APIS.ac.uk](http://www.APIS.ac.uk)) should be used to better understand atmospheric deposition at GWDTEs. We compared this modelled data to monthly site specific data collected the three GWDTEs in this study proving that modelled data provides a very cost effective (free) way assess atmospheric deposition which is most useful for country-wide screening exercises. If a higher resolution understanding of pressures area required then open access APIS data can also be compared to detailed on site NVC maps, and for the first time we looked at using these detailed NVC maps to screen for site relevant critical load exceedances. For site-specific studies, where atmospheric inputs are within around 5 kg N/ha/yr of the critical load, it is suggested that on-site measurements of ammonia (the largest contributor to the atmospheric deposition load) are made. Where atmospheric deposition data are required then triplicate on-site samples and travel blanks are essential to ensure data quality, ideally using ALPHA type badge samplers which have a much lower limit of detection and are therefore more accurate at the concentrations where additional measurements are likely to be needed. Standard commercial ammonia diffusion tubes tend to over-estimate concentrations at lower levels, potentially leading to recommendations for unnecessary remediation work if measured values suggest critical loads are exceeded. Future WFD classification rounds should consider comparing the site relevant critical loads to the modelled atmospheric deposition data at a country scale as a simple and cost effective way to screen for GWDTEs that could be under pressure from atmospheric deposition.

Nitrate loading and leaching can be modelled using freely-open access tools such as the ADAS ‘FarmScoper’ tool and the Environment Agency ‘Nitrate Loading’ tool. We successfully applied the FarmScoper tool to two of the study sites. However in both worked examples the modelling showed that even with changes in land use and application of more efficient fertilisers the results would not reduce nitrate concentrations in groundwater sufficiently for the wetland to fall below the suggested WFD threshold value.

Data-synthesis or modelling is required to quantify the proportion of atmospheric deposited N in the wider surface water and groundwater catchments which actually reaches the site. This would require knowledge of the fate and transport of N within a catchment. For this study we have assumed that all N deposited within the groundwater or surface water catchment reaches the site, however we know this is not the case and considerably overestimates the N load from atmospheric sources. Rough calculations based on Farmscoper outputs suggest that atmospheric inputs are

likely to comprise at most 20 % of the load coming from agricultural inputs. However, further work is required to refine these estimates and suggest an improved approach for quantifying the true load to groundwater from atmospheric inputs, and assessing the relative importance of atmospheric vs terrestrial inputs.

We have illustrated that there are benefits from working together across government agencies sharing resources and knowledge within teams comprising of but not limited to; ecologists, hydrologists, air quality specialists, agronomists, groundwater modellers and environmental regulators.

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## APPENDICES

**Nitrate Threshold Values**

**Critical Loads**

**APIS Source Attribution Examples**

**Diffusion Tubes**

**Inorganic Water Chemistry**

**Oxygen and Nitrogen Isotopes**

**Sample Points**

**Site Photographs**

## THRESHOLD VALUES

Groundwater Dependent Terrestrial Ecosystem Category	Low Altitude (<175mAOD)		Medium Altitude (>175mAOD)		Any Altitude	
	N mg/l	NO <sub>3</sub> mg/l	N mg/l	NO <sub>3</sub> mg/l	N mg/l	NO <sub>3</sub> mg/l
Quaking Bog	4	18	1	4		
Wet Dune					3	13
Fen (mesotrophic) and fen meadow	5	22	2	9		
Fen (oligotrophic) and Tufa forming springs	4.5	20	1	4		
Wet Grassland	6	26	2	9		
Wet Heath	3	13	2	9		
Peatbog and woodland on peatbog					2	9
Wetlands directly irrigated by spring or seepage					2	9
Swamp (mesotrophic) and reedbed					5	22
Swamp (oligotrophic)					4	18
Wet woodland	5	22	2	9		

UKTAG Threshold Values for nitrate in groundwater (UKTAG, 2012)



## CRITICAL LOADS

Habitat type	EUNIS code <sup>1</sup>	Critical load range (kg N ha <sup>-1</sup> year <sup>-1</sup> )	UK Mapping Value <sup>2</sup> (kg N ha <sup>-1</sup> year <sup>-1</sup> )	Recommended Value <sup>3</sup> (kg N ha <sup>-1</sup> year <sup>-1</sup> )
<b>Marine habitats</b>				
Mid-upper saltmarshes	A2.53	20-30 (#)	25	N/A
Pioneer & low saltmarshes	A2.54/55	20-30 (#)	25	N/A
<b>Coastal habitats</b>				
Shifting coastal dunes	B1.3	10-20 (#)	not mapped	10
Coastal stable dune grasslands	B1.4 <sup>i</sup>	8-15 #	9 acid dunes 12 non-acid dunes	8
Coastal dune heaths	B1.5	10-20 (#)	not mapped	10
Moist to wet dune slacks	B1.8 <sup>j</sup>	10-20 (#)	not mapped	10
<b>Inland surface water habitats</b>				
Softwater lakes (permanent oligotrophic)	C1.1 <sup>f</sup>	3-10 ##	not mapped	3
Permanent dystrophic lakes, ponds, pools	C1.4 <sup>i</sup>	3-10 (#)	not mapped	3
<b>Mire, bog &amp; fen habitats</b>				
Raised & blanket bogs	D1 <sup>g</sup>	5-10 ##	8,9,10 (rainfall dependent)	5
Valley mires, poor fens & transition mires	D2 <sup>j</sup>	10-15 #	not mapped	10
Rich fens	D4.1 <sup>h</sup>	15-30 (#)	not mapped	15
Montane rich fens	D4.2 <sup>j</sup>	15-25 (#)	not mapped	15
<b>Grassland &amp; tall forb habitats</b>				
Semi-dry calcareous grassland	E1.26	15-25 ##	15	15
Dry acid & neutral closed grassland	E1.7 <sup>j</sup>	10-15 ##	10	10
Inland dune pioneer grassland	E1.94 <sup>i</sup>	8-15 (#)	not mapped	8
Inland dune siliceous grassland	E1.95 <sup>i</sup>	8-15 (#)	not mapped	8
Low & medium altitude hay meadows	E2.2	20-30 (#)	not mapped	20
Mountain hay meadows	E2.3	10-20 (#)	not mapped	10
Molinia caerulea meadows	E3.51	15-25 (#)	not mapped	15
Juncus meadows & Nardus stricta swards	E3.52	10-20 #	15	10
Moss & lichen dominated mountain summits	E4.2	5-10 #	7	7
Alpine & subalpine acid grassland	E4.3	5-10 #	not mapped	5
Alpine & subalpine calcareous grassland	E4.4	5-10 #	not mapped	5
<b>Heathland, scrub &amp; tundra habitats</b>				
Arctic, alpine & subalpine scrub	F2	5-15 #	not mapped	5
Calluna dominated upland wet heaths	F4.11 <sup>ab</sup>	10-20 #	10	10
Erica tetralix dominated lowland wet heaths	F4.11 <sup>ab</sup>	10-20 (#)	10	10
Dry heaths	F4.2 <sup>ab</sup>	10-20 ##	10	10
<b>Forest habitats</b>				
Broadleaved woodland	G1	10-20 ##	12	10
Beech woodland	G1.6	10-20 (#)	15	15
Acidophilous oak dominated woodland	G1.8	10-15 (#)	10	10
Coniferous woodland	G3	5-15 ##	12	10
Scots Pine woodland	G3.4	5-15 #	12	12

Critical loads of nutrient nitrogen showing published ranges (Bobbink & Hettling, 2011) and values applied in the UK (Hall et al. 2011).

## DIFFUSION TUBES

### Gaseous N flux calculations

Deposition velocities used in the calculations are shown in the Table below. These are UK averages taken from the FRAME model. Deposition is calculated using the equation below per unit area, and converted to kg N/ha/yr.

Deposition = Elemental N concentration in air x Deposition velocity (mm/s) x time (s)

	Deposition velocity (mm/s)	
	NH3	NO2
Woodland	1.85	24.59
Moorland/grassland	1.22	19.41

Tables showing steps in the calculations

Date On	Date Off	Time (hours)	(Field) blank corrected reps NH3 (ug/m3)	Blank corrected average conc (ug/m3)	N conc (area basis g/m2)	Seconds in time period	g/m2 of N in that time	kg N/ha in that time
					3.8678E-06			
26/01/2016	01/03/2016	845.17	7.41	4.697		3042612	0.228	2.28
26/01/2016	01/03/2016	845.17	3.23					
26/01/2016	01/03/2016	845.17	3.45					

Table showing conversion factors to support the calculations above

NH3 Vd (deposition velocity) (mm/s)	19.41
Converting to m per second	0.019407166
Seconds in an hour	3600
N in NH3	0.823529412
grams in a ug	0.000001

Site	Sample		Time		ug/m3	ppb	ug NO2
	No.	Date On	Date Off	(hours)			
Wybunbury Moss 1	627992	05/11/2015	08/12/2015	790.5	5.53	2.89	0.32
Wybunbury Moss 2	627991	05/11/2015	08/12/2015	790.5	5.76	3.01	0.33
Wybunbury Moss 3	627990	05/11/2015	08/12/2015	790.5	5.69	2.97	0.33
Wybunbury Moss Blank	627993	05/11/2015	08/12/2015	790.5	0.19	0.1	0.01
Lab Blank				790.5	0.07	0.04	0.004
Wybunbury Moss 1	640468	08/12/2015	12/01/2016	843.5	10	5.22	0.61
Wybunbury Moss 2	640467	08/12/2015	12/01/2016	843.5	11.11	5.8	0.68
Wybunbury Moss 3	640466	08/12/2015	12/01/2016	843.5	11.04	5.76	0.68
Wybunbury Moss Blank	640465	08/12/2015	12/01/2016	843.5	0.17	0.09	0.01
Lab Blank				843.5	0.1	0.05	0.006
Wybunbury Moss 1	655601	12/01/2016	18/02/2016	884.5	11.82	6.17	0.76
Wybunbury Moss 2	655602	12/01/2016	18/02/2016	884.5	12.16	6.34	0.78
Wybunbury Moss 3	655603	12/01/2016	18/02/2016	884.5	13.34	6.96	0.86
Wybunbury Moss Blank	655600	12/01/2016	18/02/2016	884.5	<0.26	<0.14	<0.017
Lab Blank					0.05	0.02	0.003
Wybunbury Moss 1	673192	18/02/2016	10/03/2016	504.92	13.01	6.79	0.48
Wybunbury Moss 2	673191	18/02/2016	10/03/2016	504.92	12.18	6.35	0.45
Wybunbury Moss 3	673193	18/02/2016	10/03/2016	504.92	11.93	6.23	0.44
Wybunbury Moss Blank	673194	18/02/2016	10/03/2016	504.92	0.31	0.16	0.01
Lab Blank				504.92	0.25	0.13	0.009
Wybunbury Moss 1	687333	10/03/2016	08/04/2016	691.75	1	0.52	0.05
Wybunbury Moss 2	687332	10/03/2016	08/04/2016	691.75	0.9	0.47	0.05
Wybunbury Moss 3	687331	10/03/2016	08/04/2016	691.75	0.65	0.34	0.03
Wybunbury Moss Blank	687334	10/03/2016	08/04/2016	691.75	0.25	0.13	0.01
Lab Blank				691.75	0.12	0.06	0.006
Wybunbury Moss 1	700221	08/04/2016	10/05/2016	771.83	8.23	4.23	0.46
Wybunbury Moss 2	700220	08/04/2016	10/05/2016	771.83	8.41	4.39	0.47
Wybunbury Moss 3	700219	08/04/2016	10/05/2016	771.83	9.73	5.08	0.55
Wybunbury Moss Blank	700222	08/04/2016	10/05/2016	771.83	0.2	0.11	0.01
Lab Blank					0.09	0.05	0.005
Wybunbury Moss 1	715155	10/05/2016	09/06/2016	717.92	9.58	5	0.5
Wybunbury Moss 2	715154	10/05/2016	09/06/2016	717.92	8.98	4.69	0.47
Wybunbury Moss 3	715153	10/05/2016	09/06/2016	717.92	9.12	4.76	0.48
Wybunbury Moss Blank	715152	10/05/2016	09/06/2016	717.92	0.24	0.12	0.01
Lab Blank					0.02	0.01	0.001
Wybunbury Moss 1	7298852	09/06/2016	13/07/2016	814.92	5.33	2.78	0.32
Wybunbury Moss 2	7298854	09/06/2016	13/07/2016	814.92	4.84	2.53	0.29
Wybunbury Moss 3	7298851	09/06/2016	13/07/2016	814.92	4.91	2.56	0.29
Wybunbury Moss Blank	7298853	09/06/2016	13/07/2016	814.92	0.12	0.07	0.01
Lab Blank				814.92	0.15	0.08	0.009
Wybunbury Moss 1	745839	13/07/2016	16/08/2016	817.08	0.22	0.12	0.01
Wybunbury Moss 2	745838	13/07/2016	16/08/2016	817.08	5.85	3.05	0.35
Wybunbury Moss 3	745837	13/07/2016	16/08/2016	817.08	6.05	3.06	0.36
Wybunbury Moss Blank	745836	13/07/2016	16/08/2016	817.08	5.59	2.92	0.33
Lab Blank				817.08	0.15	0.08	0.009
Wybunbury Moss 1	760622	16/08/2016	15/09/2016	719	8.38	4.37	0.44
Wybunbury Moss 2	760621	16/08/2016	15/09/2016	719	7.74	4.04	0.4
Wybunbury Moss 3	760620	16/08/2016	15/09/2016	719	7.73	4.03	0.4
Wybunbury Moss Blank	760619	16/08/2016	15/09/2016	719	0.25	0.13	0.01
Lab Blank				719	0	0	0
Wybunbury Moss 1	775183	15/09/2016	10/10/2016	604.25	9.7	5.07	0.43
Wybunbury Moss 2	775182	15/09/2016	10/10/2016	604.25	9.86	5.14	0.43
Wybunbury Moss 3	775181	15/09/2016	10/10/2016	604.25	9.26	4.85	0.41
Wybunbury Moss Blank	775180	15/09/2016	10/10/2016	604.25	0.3	0.16	0.01
Lab Blank			10/10/2016	604.25	0.16	0.08	0.007
Wybunbury Moss 1	790791	10/10/2016	14/11/2016	836.75	13.08	6.83	0.8
Wybunbury Moss 2	790790	10/10/2016	14/11/2016	836.75	12.31	6.43	0.75
Wybunbury Moss 3	79089	10/10/2016	14/11/2016	836.75	12.32	6.43	0.75
Wybunbury Moss Blank	790788			836.75	0.14	0.07	0.01
Lab Blank				836.75	0.1	0.05	0.006
Wybunbury Moss 1	809905	14/11/2016	15/12/2016	743.25	18.06	9.43	0.98
Wybunbury Moss 2	809904	14/11/2016	15/12/2016	743.25	17.44	9.1	0.94
Wybunbury Moss 3	809903	14/11/2016	15/12/2016	743.25	17.45	9.11	0.94
Wybunbury Moss Blank	809906	14/11/2016	15/12/2016	743.25	0.12	0.06	0.01
Lab Blank				743.25	0.09	0.05	0.005

## Wybunbury Moss NO<sub>2</sub>

Location	Sample Number	Date On	Date Off	Time (hours)	ug NH4 TOTAL	ug NH3 Total	ug NH3	NH3 ug/m3	NH3 ppb
Wybunbury Moss Left	628000	05/11/2015	08/12/2015	790.5	0.47	0.44	0.35	2.75	3.87
Wybunbury Moss middle	627999	05/11/2015	08/12/2015	790.5	0.45	0.42	0.34	2.62	3.69
Wybunbury Moss Right	627998	05/11/2015	08/12/2015	790.5	0.41	0.38	0.3	2.31	3.26
Wybunbury Moss Blank	627997			0.09	0.09				
Lab Blank				0.01	0.01				
Wybunbury Moss 1	640473	08/12/2015	12/01/2016	843.67	0.42	0.4	0.36	2.6	3.67
Wybunbury Moss 2	640472	08/12/2015	12/01/2016	843.67	0.51	0.48	0.44	3.19	4.5
Wybunbury Moss 3	640471	08/12/2015	12/01/2016	843.67	0.46	0.43	0.39	2.84	4
Wybunbury Moss Blank				0.04	0.04				
Lab Blank				0.01	0.01				
Wybunbury Moss 1	655591	12/01/2016	18/02/2016	884.5	0.62	0.59	0.49	3.43	4.84
Wybunbury Moss 2	655592	12/01/2016	18/02/2016	884.5	0.6	0.56	0.47	3.27	4.62
Wybunbury Moss 3	655593	12/01/2016	18/02/2016	884.5	0.54	0.51	0.41	2.89	4.07
Wybunbury Moss Blank	655590				0.1	0.1			
Lab Blank					0.02	0.02			
Wybunbury Moss 1	673203	18/02/2016	10/03/2016	504.92	0.39	0.36	0.29	3.53	4.98
Wybunbury Moss 2	673202	18/02/2016	10/03/2016	504.92	0.43	0.4	0.33	4.01	5.65
Wybunbury Moss 3	673201	18/02/2016	10/03/2016	504.92	0.39	0.37	0.29	3.56	5.03
Wybunbury Moss Blank	673204				0.08	0.07			
Lab Blank					0.01	0.01			
Wybunbury Moss 1	687343	10/03/2016	08/04/2016	691.75	0.96	0.91	0.78	6.92	9.76
Wybunbury Moss 2	687342	10/03/2016	08/04/2016	691.75	0.99	0.93	0.8	7.12	10.04
Wybunbury Moss 3	687341	10/03/2016	08/04/2016	691.75	1.01	0.95	0.82	7.31	10.31
Wybunbury Moss Blank	687341				0.14	0.13			
Lab Blank					0.02	0.02			
Wybunbury Moss 1		08/04/2016	10/05/2016	771.83	0.75	0.71	0.6	4.83	6.81
Wybunbury Moss 2		08/04/2016	10/05/2016	771.83	0.73	0.69	0.59	4.68	6.6
Wybunbury Moss 3		08/04/2016	10/05/2016	771.83	0.73	0.68	0.58	4.64	6.54
Wybunbury Moss Blank					0.11	0.1			
Lab Blank					0.02	0.02			
Wybunbury Moss 1	715165	10/05/2016	09/06/2016	717.92	0.72	0.68	0.55	4.7	6.63
Wybunbury Moss 2	715164	10/05/2016	09/06/2016	717.92	0.73	0.69	0.55	4.77	6.72
Wybunbury Moss 3	715163	10/05/2016	09/06/2016	717.92	0.69	0.65	0.52	4.47	6.3
Wybunbury Moss Blank	715162				0.14	0.13			
Lab Blank					0.01	0.01			
Wybunbury Moss 1	729863	09/06/2016	13/07/2016	814.92	0.53	0.5	0.49	3.69	5.21
Wybunbury Moss 2	729862	09/06/2016	13/07/2016	814.92	0.52	0.52	0.49	3.68	5.19
Wybunbury Moss 3	729861	09/06/2016	13/07/2016	814.92	0.57	0.54	0.53	3.98	5.62
Wybunbury Moss Blank	729864	09/06/2016	13/07/2016	814.92	0.22	0.2	0.19	1.47	2.07
Lab Blank					0.01	0.01			
Wybunbury Moss 1	745848	13/07/2016	16/08/2016	817.08	0.79	0.75	0.73	5.53	7.79
Wybunbury Moss 2	745847	13/07/2016	16/08/2016	817.08	0.77	0.73	0.72	5.4	7.61
Wybunbury Moss 3	745846	13/07/2016	16/08/2016	817.08	0.76	0.72	0.7	5.31	7.48
Wybunbury Moss Blank	745849	13/07/2016	16/08/2016	817.08	0.27	0.25	0.24	1.81	2.56
Lab Blank					0.01	0.01			
Wybunbury Moss 1	745848	16/08/2016	15/09/2016	719	0.78	0.74	0.72	6.21	8.76
Wybunbury Moss 2	745847	16/08/2016	15/09/2016	719	0.77	0.73	0.71	6.12	8.62
Wybunbury Moss 3	745846	16/08/2016	15/09/2016	719	0.81	0.77	0.75	6.47	9.12
Wybunbury Moss Blank	745849	16/08/2016	15/09/2016	719	0.27	0.26	0.24	2.08	2.93
Lab Blank					0.01	0.01			
Wybunbury Moss 1	775193	15/09/2016	10/10/2016	604.25	0.62	0.59	0.56	5.69	8.02
Wybunbury Moss 2	775192	15/09/2016	10/10/2016	604.25	0.57	0.53	0.5	5.14	7.25
Wybunbury Moss 3	775191	15/09/2016	10/10/2016	604.25	0.65	0.61	0.58	5.91	8.34
Wybunbury Moss Blank	775190	15/09/2016	10/10/2016	604.25	0.26	0.24	0.21	2.16	3.05
Lab Blank									
Wybunbury Moss 1	790801	10/10/2016	14/11/2016	836.75	1.11	1.05	1.03	7.56	10.66
Wybunbury Moss 2	790800	10/10/2016	14/11/2016	836.75	0.64	0.64	0.58	4.27	6.02
Wybunbury Moss 3	790799	10/10/2016	14/11/2016	836.75	0.65	0.65	0.59	4.33	6.1
Wybunbury Moss Blank	790798	10/10/2016	14/11/2016	836.75	0.31	0.31	0.26	1.95	2.75
Lab Blank					0.03	0.02			
Wybunbury Moss 1	809915	14/11/2016	15/12/2016	743.25	0.57	0.54	0.42	3.44	4.85
Wybunbury Moss 2	809914	14/11/2016	15/12/2016	743.25	0.55	0.52	0.4	3.29	4.63
Wybunbury Moss 3	809913	14/11/2016	15/12/2016	743.25	0.55	0.52	0.4	3.31	4.67
Wybunbury Moss Blank	809916	14/11/2016	15/12/2016	743.25	0.13	0.12			
Lab Blank					743.25	0.02	0.02		

## Wybunbury Moss NH<sub>3</sub>

Location	Sample		Time		ug/m3	ppb	ug NO2
	Number	Date On	Date Off	(hours)			
Newbald Beckies,	627967	05/11/2015	08/12/2015	789.42	14.77	7.71	0.85
Newbald Beckies,	627968	05/11/2015	08/12/2015	789.42	11.98	6.25	0.69
Newbald Beckies,	627969	05/11/2015	08/12/2015	789.42	14.75	7.7	0.85
Newbald Beckies, BLANK	627966	05/11/2015	08/12/2015	789.42	0.24	0.12	0.01
Lab Blank					0.09	0.05	0.005
Newbald Beckies,	640474	08/12/2015	15/01/2016	913.67	15.83	8.26	1.05
Newbald Beckies,	640475	08/12/2015	15/01/2016	913.67	13.87	7.24	0.92
Newbald Beckies,	640476	08/12/2015	15/01/2016	913.67	14.27	7.45	0.95
Newbald Beckies, BLANK	640477	08/12/2015	15/01/2016	913.67	0.08	0.04	0.01
Lab Blank				913.67	0.27	0.14	0.018
Newbald Beckies,	655605	15/01/2016	01/03/2016	1106.42	13.39	6.99	1.08
Newbald Beckies,	655606	15/01/2016	01/03/2016	1106.42	15.38	8.03	1.24
Newbald Beckies, BLANK	655607	15/01/2016	01/03/2016	1106.42	14.14	7.38	1.14
Newbald Beckies,	655604	15/01/2016	01/03/2016	1106.42	0.16	0.08	0.01
Laboratory Blank					0.05	0.03	0.004
Newbald Beckies,	673185	01/03/2016	01/04/2016	745.42	0.18	0.09	0.01
Newbald Beckies,	673186	01/03/2016	01/04/2016	745.42	9.01	4.7	0.49
Newbald Beckies, BLANK	673187	01/03/2016	01/04/2016	745.42	10.24	5.34	0.55
Newbald Beckies,	673188	01/03/2016	01/04/2016	745.42	9.65	5.04	0.52
Laboratory Blank					0.11	0.06	0.006
Newbald Beckies,	697422	01/04/2016	03/05/2016	770.00	7.39	3.85	0.41
Newbald Beckies,	697423	01/04/2016	03/05/2016	770.00	8.57	4.47	0.48
Newbald Beckies, BLANK	697424	01/04/2016	03/05/2016	770.00	7.78	4.06	0.44
Newbald Beckies,	697421	01/04/2016	03/05/2016	770.00	0.26	0.14	0.01
Laboratory Blank				770.00	0.13	0.07	0.007
Newbald Beckies,	715155	10/05/2016	09/06/2016	717.92	9.58	5	0.5
Newbald Beckies,	715155	10/05/2016	09/06/2016	717.92	8.98	4.69	0.47
Newbald Beckies,	715153	10/05/2016	09/06/2016	717.92	9.12	4.76	0.48
Newbald Beckies, Blank	715152			717.92	0.24	0.12	0.01
Laboratory Blank				717.92	0.02	0.01	0.001
Newbald Beckies,	728395	07/06/2016	01/07/2016	572.83	4.51	2.36	0.19
Newbald Beckies,	728396	07/06/2016	01/07/2016	572.83	4.96	2.59	0.21
Newbald Beckies,	728397	07/06/2016	01/07/2016	572.83	4.37	2.28	0.18
Newbald Beckies, Blank	728394			572.83	0.19	0.1	0.01
Lab Blank				572.83	0.17	0.09	0.007
Newbald Beckies,	745831	01/07/2016	01/08/2016	743.8	6.22	3.25	0.34
Newbald Beckies,	745832	01/07/2016	01/08/2016	743.8	5.91	3.09	0.32
Newbald Beckies,	745833	01/07/2016	01/08/2016	743.8	6.81	3.55	0.37
Newbald Beckies, Blank	745830			743.8	0.18	0.09	0.01
Lab Blank				743.8	0.13	0.07	0.007
Newbald Beckies,	760623	01/08/2016	15/09/2016	1082.25	7.72	4.03	0.61
Newbald Beckies,	760624	01/08/2016	15/09/2016	1082.25	7.86	4.1	0.62
Newbald Beckies,	760625	01/08/2016	15/09/2016	1082.25	8.86	4.62	0.7
Newbald Beckies, Blank	760626	01/08/2016	15/09/2016	1082.25	0.15	0.08	0.01
Lab Blank				1082.25	0.06	0.03	0.005
Newbald Beckies,	775049	15/09/2016	17/10/2016	765.88	7.03	3.67	0.39
Newbald Beckies,	775050	15/09/2016	17/10/2016	765.88	8.11	4.23	0.45
Newbald Beckies,	775051	15/09/2016	17/10/2016	765.88	7.28	3.8	0.41
Newbald Beckies, Blank	775048	15/09/2016	17/10/2016	765.88	0.13	0.07	0.01
Lab Blank				765.88	0.07	0.04	0.004
Newbald Beckies,		17/10/2016	24/11/2016	912.97	11.57	6.04	0.77
Newbald Beckies,		17/10/2016	24/11/2016	912.97	12.37	6.46	0.82
Newbald Beckies,		17/10/2016	24/11/2016	912.97	13.64	7.12	0.91
Newbald Beckies, Blank		17/10/2016	24/11/2016	912.97	0.42	0.22	0.03
Lab Blank				912.97	0.08	0.04	0.005
Newbald Beckies,	809898	24/11/2016	19/12/2016	599.55	20.22	10.55	0.88
Newbald Beckies,	809899	24/11/2016	19/12/2016	599.55	21.02	10.97	0.92
Newbald Beckies,	809900	24/11/2016	19/12/2016	599.55	19.41	10.13	0.85
Newbald Beckies, Blank	809897			599.55	0.2	0.1	0.01
Lab Blank				599.55	0	0	0

## Newbald Beckies NO<sub>2</sub>



	Sample			Time	ug NH4	ug NH3	ug	NH3	NH3
Location	Number	Date On	Date Off	(hours)	TOTAL	Totoal	NH3	ug/m3	ppb
Newbald Beckies,	627977	05/11/2015	08/12/2015	789.42	0.37	0.34	0.22	1.75	2.46
Newbald Beckies,	627978	05/11/2015	08/12/2015	789.42	0.38	0.36	0.24	1.89	2.66
Newbald Beckies,	627979	05/11/2015	08/12/2015	789.42	0.36	0.34	0.22	1.74	2.46
Travel Blank	627976				0.13	0.12			
Lab Blank					0.01	0.01			
Newbald Beckies,	640474	08/12/2015	15/01/2016	913.7	0.14	0.13	0.06	0.42	0.59
Newbald Beckies,	640475	08/12/2015	15/01/2016	913.7	0.33	0.31	0.24	1.16	2.27
Newbald Beckies,	640476	08/12/2015	15/01/2016	913.7	0.3	0.28	0.21	1.43	2.02
Newbald Beckies, BLANK	640477				0.07	0.07			
Lab Blank					0.01	0.01			
Newbald Beckies,	655595	15/01/2016	01/03/2016	1106.3	0.77	0.72	0.58	3.24	4.57
Newbald Beckies,	655596	15/01/2016	01/03/2016	1106.3	0.8	0.75	0.61	3.39	4.77
Newbald Beckies,	655597	15/01/2016	01/03/2016	1106.3	0.87	0.82	0.67	3.75	5.29
Newbald Beckies, BLANK	655594				0.15	0.14			
Lab Blank					0.01	0.01			
Newbald Beckies,	673196	01/03/2016	01/04/2016	745.58	1.27	1.2	1.06	8.76	12.35
Newbald Beckies,	673197	01/03/2016	01/04/2016	745.58	1.36	1.28	1.14	9.43	13.29
Newbald Beckies,	673198	01/03/2016	01/04/2016	745.58	1.2	1.13	0.99	8.18	11.53
Newbald Beckies, BLANK	673195				0.15	0.14			
Lab Blank					0.02	0.02			
Newbald Beckies,	697427	01/04/2016	07/06/2016	770	1.1	1.04	0.87	6.97	9.83
Newbald Beckies,	697428	01/04/2016	07/06/2016	770	1.11	1.05	0.89	7.09	9.99
Newbald Beckies,	697429	01/04/2016	07/06/2016	770	1.08	1.02	0.85	6.81	9.6
Newbald Beckies, BLANK	697426				0.18	0.17			
Lab Blank					0.02	0.02			
Newbald Beckies,	728400	07/06/2016	01/07/2016	572.85	0.37	0.35	0.19	2.04	2.87
Newbald Beckies,	728401	07/06/2016	01/07/2016	572.85	0.4	0.38	0.22	2.35	3.31
Newbald Beckies,	728402	07/06/2016	01/07/2016	572.85	0.42	0.4	0.23	2.51	3.54
Newbald Beckies, BLANK	728399				0.17	0.16			
Lab Blank					0.01	0.01			
Newbald Beckies,	745841	01/07/2016	01/08/2016	743.75	0.46	0.43	0.4	3.27	4.62
Newbald Beckies,	745842	01/07/2016	01/08/2016	743.75	0.49	0.47	0.43	3.54	4.99
Newbald Beckies,	745843	01/07/2016	01/08/2016	743.75	0.46	0.44	0.4	3.3	4.65
Newbald Beckies, BLANK	745840	01/07/2016	01/08/2016	743.75	0.18	0.17	0.13	1.1	1.55
Lab Blank					0.04	0.04			
Newbald Beckies,	760634	01/08/2016	15/09/2016	1082.3	1.24	1.17	0.97	5.53	7.79
Newbald Beckies,	760635	01/08/2016	15/09/2016	1082.3	1.34	1.27	1.07	6.11	8.61
Newbald Beckies,	760636	01/08/2016	15/09/2016	1082.3	1.24	1.18	0.98	5.58	7.86
Newbald Beckies, BLANK	760633	01/08/2016	15/09/2016	1082.3	0.21	0.2			
Lab Blank					0.01	0.01			
Newbald Beckies,	775044	15/09/2016	17/10/2016	765.88	0.52	0.49	0.32	2.59	3.66
Newbald Beckies,	775045	15/09/2016	17/10/2016	765.88	0.48	0.45	0.28	2.29	3.23
Newbald Beckies,	775046	15/09/2016	17/10/2016	765.88	0.47	0.44	0.27	2.21	3.11
Newbald Beckies, Blank	775043	15/09/2016	17/10/2016	765.88	0.13	0.17			
Lab Blank				765.88	0.03	0.03			
Newbald Beckies,	790793	17/10/2016	24/11/2016	912.97	0.53	0.5	0.49	3.28	4.63
Newbald Beckies,	790794	17/10/2016	24/11/2016	912.97	0.82	0.77	0.76	5.1	7.19
Newbald Beckies,	790795	17/10/2016	24/11/2016	912.97	0.95	0.9	0.88	5.92	8.35
Newbald Beckies, Blank	790792	17/10/2016	24/11/2016	912.97	0.44	0.41	0.39	2.67	3.76
Lab Blank					0.02	0.02			
Newbald Beckies,	789340	24/11/2016	19/12/2016	599.55	0.4	0.38	0.3	3.04	4.29
Newbald Beckies,	789341	24/11/2016	19/12/2016	599.55	0.35	0.33	0.25	2.56	3.61
Newbald Beckies,	789342	24/11/2016	19/12/2016	599.55	0.32	0.3	0.21	2.21	3.12
Newbald Beckies, Blank	809907	24/11/2016	19/12/2016	599.55	0.09	0.09			
Lab Blank					0.02	0.02			

## Newbald Beckies NH<sub>3</sub>

Location	Sample		Time		ug/m3	ppb	ug NO2
	Number	Date On	Date Off	(hours)			
Newbald Water Compound	671411	26/01/2016	01/03/2016	845.22	0.39	0.2	0.02
Newbald Water Compound	671412	26/01/2016	01/03/2016	845.22	13.83	7.22	0.85
Newbald Water Compound	671413	26/01/2016	01/03/2016	845.22	12.95	6.76	0.8
Newbald Water Compound Blank	671414	26/01/2016	01/03/2016	845.22	14.52	7.58	0.89
Lab Blank				845.22	0.13	0.07	0.008
Newbald Water Compound	686661	01/03/2016	01/04/2016	742.08	<0.19	0.1	0.01
Newbald Water Compound	686662	01/03/2016	01/04/2016	742.08	9.12	4.76	0.49
Newbald Water Compound	686662	01/03/2016	01/04/2016	742.08	10.21	5.33	0.55
Newbald Water Compound Blank	686664	01/03/2016	01/04/2016	742.08	9.97	5.11	0.53
Lab Blank				742.08	0.17	0.09	0.009
Newbald Water Compound	687335	01/04/2016	03/05/2016	770.25	0.16	0.08	0.01
Newbald Water Compound	687336	01/04/2016	03/05/2016	770.25	9.08	4.74	0.51
Newbald Water Compound	687337	01/04/2016	03/05/2016	770.25	8.38	4.38	0.47
Newbald Water Compound Blank	687338	01/04/2016	03/05/2016	770.25	8.15	4.25	0.46
Lab Blank				770.25	0.09	0.05	0.005
Newbald Water Compound	700214	03/05/2016	07/06/2016	840.83	6.77	3.54	0.41
Newbald Water Compound	700215	03/05/2016	07/06/2016	840.83	6.78	3.54	0.41
Newbald Water Compound	700216	03/05/2016	07/06/2016	840.83	6.13	3.2	0.37
Newbald Water Compound Blank	700213	03/05/2016	07/06/2016	840.83	0.24	0.13	0.01
Lab Blank				840.83	0.36	0.19	0.022
Newbald Water Compound	715157	07/06/2016	01/07/2016	572.95	6.36	3.32	0.27
Newbald Water Compound	715158	07/06/2016	01/07/2016	572.95	6.67	3.48	0.28
Newbald Water Compound	971515	07/06/2016	01/07/2016	572.95	5.84	3.05	0.24
Newbald Water Compound Blank	615157			572.95	0.48	0.25	0.02
Lab Blank				572.95	0.17	0.09	0.007
Newbald Water Compound	743526	01/07/2016	01/08/2016	743.58	8.19	4.28	0.44
Newbald Water Compound	743527	01/07/2016	01/08/2016	743.58	8.4	4.38	0.45
Newbald Water Compound	743528	01/07/2016	01/08/2016	743.58	8.21	4.28	0.44
Newbald Water Compound Blank	743525	01/07/2016	01/08/2016	743.58	0.21	0.11	0.01
Lab Blank				743.58	0.06	0.03	0.003
Newbald Water Compound	758247	01/08/2016	15/09/2016	1083	9.31	4.86	0.73
Newbald Water Compound	758248	01/08/2016	15/09/2016	1083	9.01	4.7	0.71
Newbald Water Compound	758249	01/08/2016	15/09/2016	1083	9.37	4.89	0.74
Newbald Water Compound Blank	758250	01/08/2016	15/09/2016	1083	0.2	0.1	0.02
Lab Blank				1083	0.06	0.03	0.005
Newbald Water Compound	775184	15/09/2016	17/10/2016	765.92	148.8	77.7	0.5
Newbald Water Compound	775185	15/09/2016	17/10/2016	765.92	143.7	75	0.48
Newbald Water Compound	775186	15/09/2016	17/10/2016	765.92	125.3	65.4	0.42
Newbald Water Compound Blank	775187			765.92	2.25	1.17	0.01
Lab Blank				765.92	1.2	0.63	0.004
Newbald Water Compound	789335	17/10/2016	24/11/2016	913.9	15.74	8.22	1.05
Newbald Water Compound	789336	17/10/2016	24/11/2016	913.9	14.83	7.74	0.99
Newbald Water Compound	789337	17/10/2016	24/11/2016	913.9	14.49	7.56	0.96
Newbald Water Compound Blank	789334			913.9	0.1	0.05	0.01
Lab Blank				913.9	0.09	0.05	0.006
Newbald Water Compound	809898	24/11/2016	19/12/2016	568.4	20.22	10.6	0.88
Newbald Water Compound	809899	24/11/2016	19/12/2016	568.4	21.02	11	0.92
Newbald Water Compound	809900	24/11/2016	19/12/2016	568.4	19.41	10.1	0.85
Newbald Water Compound Blank	809897			568.4	0.2	0.1	0.01
Lab Blank				568.4	0	0	0
Newbald Water Compound	832883	19/12/2016	20/01/2017	769.32	21.55	11.3	1.21
Newbald Water Compound	832884	19/12/2016	20/01/2017	769.32	22.7	11.9	1.27
Newbald Water Compound	832885	19/12/2016	20/01/2017	769.32	21.34	11.1	1.19
Newbald Water Compound Blank	832882				0.14	0.07	0.01
Lab Blank					0.2	0.1	0.011
Newbald Water Compound	835828	20/01/2017	20/02/2017	740.82	18.96	9.9	1.02
Newbald Water Compound	835829	20/01/2017	20/02/2017	740.82	21.89	11.4	1.18
Newbald Water Compound	835830	20/01/2017	20/02/2017	740.82	18.89	9.86	1.02
Newbald Water Compound Blank	835827			740.82	0.09	0.05	0
Lab Blank					0.17	0.09	0.009

## Newbald Water Compound NO<sub>2</sub>

Location	Sample Number	Date On	Date Off	Time (hours)	ug NH4	ug NH3	ug	NH3	NH3
					TOTAL	Totoal	NH3	ug/m3	ppb
Newbald Water Compound	671407	26/01/2016	01/03/2016	845.17	1.18	1.11	1.02	7.41	10.45
Newbald Water Compound	671408	26/01/2016	01/03/2016	845.17	0.57	0.54	0.44	3.23	4.55
Newbald Water Compound	671409	26/01/2016	01/03/2016	845.17	0.6	0.57	0.47	3.45	4.86
Travel Blank	671406				0.1	0.1			
Lab Blank					0.01	0.01			
Newbald Water Compound	686667	01/03/2016	01/04/2016	742.25	1.68	1.59	1.48	12.31	17.35
Newbald Water Compound	686668	01/03/2016	01/04/2016	742.25	1.66	1.57	1.46	12.15	17.12
Newbald Water Compound	686669	01/03/2016	01/04/2016	742.25	1.71	1.61	1.51	12.52	17.65
Travel Blank	686666				0.11	0.1			
Lab Blank					0.02	0.02			
Newbald Water Compound	687346	01/04/2016	03/05/2016	770.17	1.91	1.8	1.69	13.55	19.11
Newbald Water Compound	687347	01/04/2016	03/05/2016	770.17	1.9	1.79	1.68	13.46	18.98
Newbald Water Compound	687348	01/04/2016	03/05/2016	770.17	1.86	1.76	1.65	13.19	18.6
Travel Blank	687345				0.12	0.11			
Lab Blank					0.02	0.02			
Newbald Water Compound	700224	03/05/2016	07/06/2016	840.83	0.79	0.74	0.63	4.61	6.5
Newbald Water Compound	700225	03/05/2016	07/06/2016	840.83	0.83	0.78	0.67	4.91	6.92
Newbald Water Compound	700226	03/05/2016	07/06/2016	840.83	0.77	0.73	0.61	4.49	6.33
Travel Blank	700223				0.12	0.12			
Lab Blank					0.01	0.01			
Newbald Water Compound	71567	07/06/2016	01/07/2016	572.98	0.46	0.44	0.24	2.26	3.69
Newbald Water Compound	715168	07/06/2016	01/07/2016	572.98	0.48	0.45	0.26	2.82	3.97
Newbald Water Compound	715169	07/06/2016	01/07/2016	572.98	0.43	0.4	0.21	2.26	3.19
Travel Blank	715166				0.2	0.19			
Lab Blank					0.01	0.01			
Newbald Water Compound	743531	01/07/2016	01/08/2016	743.58	0.62	0.59	0.55	4.54	6.4
Newbald Water Compound	743532	01/07/2016	01/08/2016	743.58	0.55	0.52	0.48	3.97	5.6
Newbald Water Compound	743533	01/07/2016	01/08/2016	743.58	0.53	0.5	0.46	3.82	5.38
Travel Blank	743530	01/07/2016	01/08/2016	743.58	0.22	0.21	0.17	1.38	1.95
Lab Blank					0.04	0.04			
Newbald Water Compound	758253	01/08/2016	15/09/2016		0.99	0.94	0.92	5.25	7.4
Newbald Water Compound	758254	01/08/2016	15/09/2016		0.99	0.94	0.92	5.26	7.42
Newbald Water Compound	758255	01/08/2016	15/09/2016		0.98	0.92	0.91	5.18	7.3
Travel Blank	758252	01/08/2016	15/09/2016		0.27	0.26	0.24	1.39	1.97
Lab Blank					0.01	0.01			
Newbald Water Compound	775184	15/09/2016	17/10/2016	765.92	0.6	0.57	0.41	3.27	4.61
Newbald Water Compound	775185	15/09/2016	17/10/2016	765.92	0.62	0.59	0.43	3.45	4.86
Newbald Water Compound	775186	15/09/2016	17/10/2016	765.92	0.56	0.53	0.37	3	4.22
Travel Blank	775187				0.17	0.16			
Lab Blank					0.03	0.03			
Newbald Water Compound	809908	17/10/2016	24/11/2016	913.9	0.45	0.42	0.29	1.94	2.74
Newbald Water Compound	809909	17/10/2016	24/11/2016	913.9	0.46	0.43	0.3	2.01	2.83
Newbald Water Compound	809910	17/10/2016	24/11/2016	913.9	0.45	0.42	0.29	1.93	2.72
Travel Blank	789339			913.9	0.14	0.13			
Lab Blank				913.9	0.02	0.02			
Newbald Water Compound	803737	24/11/2016	19/12/2016	568.4	0.49	0.46	0.3	3.14	4.43
Newbald Water Compound	803738	24/11/2016	19/12/2016	568.4	0.42	0.4	0.24	2.49	3.51
Newbald Water Compound	803739	24/11/2016	19/12/2016	568.4	0.41	0.39	0.23	2.38	3.36
Travel Blank	803736				0.13	0.15			
Lab Blank					0.02	0.02			
Newbald Water Compound	821839	19/12/2016	20/01/2017	769.32	0.49	0.47	0.34	2.7	3.81
Newbald Water Compound	821840	19/12/2016	20/01/2017	769.32	0.4	0.38	0.25	1.99	2.8
Newbald Water Compound	821841	19/12/2016	20/01/2017	769.32	0.51	0.49	0.36	2.86	4.03
Travel Blank					0.14	0.13			
Lab Blank					0.02	0.02			
Newbald Water Compound	835834	20/01/2017	20/02/2017	740.67	0.48	0.45	0.32	2.67	3.76
Newbald Water Compound	835835	20/01/2017	20/02/2017	740.67	0.45	0.42	0.29	2.42	3.41
Newbald Water Compound	835836	20/01/2017	20/02/2017	740.67	0.4	0.38	0.25	2.04	2.88
Travel Blank	835833				0.14	0.13			
Lab Blank					0.03	0.02			

## Newbald Water Compound NH<sub>3</sub>

Site	Sample		Time		ug/m3	ppb	ug NO2
	No.	Date On	Date Off	(hours)			
Cors Bodeilo	5994 06	23/09/2015	31/10/2015	911.17	3.81	1.99	0.25
Cors Bodeilo	599407	23/09/2015	31/10/2015	911.17	4.44	2.32	0.29
Cors Bodeilo	599408	23/09/2015	31/10/2015	911.17	3.95	2.06	0.26
Cors Bodeilo	599409	23/09/2015	31/10/2015	911.17	4.16	2.17	0.28
Cors Bod Lab Blank				911.17	0.03	0.02	0.002
Cors Bodeilo	638372	28/11/2015	07/02/2016	1709.25	3.32	1.73	0.41
Cors Bodeilo	638371	28/11/2015	07/02/2016	1709.25	3.3	1.72	0.41
Cors Bodeilo	638370	28/11/2015	07/02/2016	1709.25	2.85	1.49	0.35
Cors Bodeilo	638369	28/11/2015	07/02/2016	1709.25	3.34	1.74	0.41
Travel Blank	638368	28/11/2015	07/02/2016	1709.25	0.08	0.04	0.01
Lab Blank				1709.25	0.06	0.03	0.008
Cors Bodeilo	724397	01/07/2016	01/08/2016	720	2.17	1.13	0.11
Cors Bodeilo	724396	01/07/2016	01/08/2016	720	2.25	1.17	0.12
Cors Bodeilo	724395	01/07/2016	01/08/2016	720	2.36	1.23	0.12
Cors Bodeilo				720	0.11	0.06	0.01
Travel Blank				720	0.13	0.07	0.007
Lab Blank							
Cors Bodeilo	755981	01/08/2016	30/08/2016	697	1.91	1	0.1
Cors Bodeilo	755982	01/08/2016	30/08/2016	697	3.5	1.82	0.18
Cors Bodeilo	755983	01/08/2016	30/08/2016	697	3.17	1.65	0.16
Cors Bodeilo	755984	01/08/2016	30/08/2016	697	4.99	2.61	0.25
Lab Blank				697	0.18	0.09	0.009
Cors Bodeilo	769601	30/08/2016	29/09/2016	720	2.86	1.49	0.15
Cors Bodeilo	769602	30/08/2016	29/09/2016	720	2.62	1.37	0.14
Cors Bodeilo	769603	30/08/2016	29/09/2016	720	2.89	1.51	0.15
Travel Blank	769604	30/08/2016	29/09/2016	720	0.12	0.06	0.01
Lab Blank				720	0.08	0.04	0.004
Cors Bodeilo	786050	29/09/2016	26/10/2016	643	6.72	3.51	0.31
Cors Bodeilo	786051	29/09/2016	26/10/2016	643	7.04	3.67	0.33
Cors Bodeilo	786052	29/09/2016	26/10/2016	643	7.33	3.83	0.34
Travel Blank	786053			643	0.21	0.11	0.01
Lab Blank				643	0.15	0.08	0.007
Cors Bodeilo	797986	26/10/2016	29/11/2016	820	6.61	3.45	0.39
Cors Bodeilo	797985	26/10/2016	29/11/2016	820	6.77	3.53	0.4
Cors Bodeilo	797984	26/10/2016	29/11/2016	820	5.99	3.13	0.36
Travel Blank	797987			820	0.18	0.1	0.01
Lab Blank				820	0.02	0.01	0.001

## Cors Bodeilo NO<sub>2</sub>

Site	Sample No.	Date On	Date Off	Time (hours)	ug NH4 TOTAL	ug NH3 Totoal	ug NH3	NH3 ug/m3	NH3 ppb
Cors Bodeilo	599416	23/09/2015	31/10/2015	911.7	0.51	0.48	0.47	3.19	4.49
Cors Bodeilo	599417	23/09/2015	31/10/2015	911.7	0.45	0.42	0.41	2.8	3.95
Cors Bodeilo	599418	23/09/2015	31/10/2015	911.7	0.47	0.45	0.44	2.98	4.21
Lab Blank					0.01	0.01			
Cors Bodeilo	650945	28/11/2015	07/02/2016	1709.25	0.43	0.41	0.4	1.43	2.01
Cors Bodeilo	650944	28/11/2015	07/02/2016	1709.25	0.5	0.47	0.46	1.66	2.34
Cors Bodeilo	650943	28/11/2015	07/02/2016	1709.25	0.49	0.46	0.45	1.61	2.27
Lab Blank					0.02	0.02			
Cors Bodeilo	739125	01/07/2016	01/08/2016	743	0.36	0.36	0.3	2.53	3.57
Cors Bodeilo	739126	01/07/2016	01/08/2016	743	0.34	0.34	0.28	2.36	3.33
Cors Bodeilo	739127	01/07/2016	01/08/2016	743	0.32	0.32	0.26	2.16	3.04
Blank	739124	01/07/2016	01/08/2016	743	0.18	0.18	0.13	1.11	1.57
lab blank					0.04	0.04			
Cors Bodeilo	755986	01/08/2016	30/08/2016	697	0.44	0.42	0.25	2.18	3.08
Cors Bodeilo	755987	01/08/2016	30/08/2016	697	0.44	0.41	0.24	2.16	3.05
Cors Bodeilo	755988	01/08/2016	30/08/2016	697	0.38	0.36	0.19	1.68	2.37
Travel Blank	755989				0.18	0.17			
Lab Blank					0.01	0.01			
Cors Bodeilo	769607	30/08/2016	29/09/2016	720	0.33	0.32	0.14	1.16	1.63
Cors Bodeilo	769608	30/08/2016	29/09/2016	720	0.34	0.32	0.14	1.21	1.71
Cors Bodeilo	769609	30/08/2016	29/09/2016	720	0.34	0.32	0.14	1.22	1.73
Travel Blank					0.19	0.18			
Lab Blank					0.03	0.03			
Cors Bodeilo	786060	29/09/2016	26/10/2016	643	0.4	0.38	0.25	2.36	3.33
Cors Bodeilo	786059	29/09/2016	26/10/2016	643	0.35	0.33	0.2	1.88	2.65
Cors Bodeilo	786058	29/09/2016	26/10/2016	643	0.35	0.33	0.2	1.87	2.64
Travel Blank	786056				0.14	0.14			
Lab Blank					0.03	0.02			
Cors Bodeilo	797992	26/10/2016	29/11/2016	820	0.37	0.35	0.33	2.49	3.52
Cors Bodeilo	797991	26/10/2016	29/11/2016	820	0.44	0.41	0.39	2.95	4.15
Cors Bodeilo	797990	26/10/2016	29/11/2016	820	0.44	0.42	0.4	2.99	4.22
Travel Blank	797993				0.26	0.24			
Lab Blank					0.02	0.02			

### Cors Bodeilio NH<sub>3</sub>

# INORGANIC WATER CHEMISTRY

WIMS	Sample Point	Type	Date	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Chloride	Sulphate	Ionic Balance	pH	Temperature	Cond @ 25C	Oxygen Dissolved	Oxygen Dissolved	Nitrate N	Nitrite N	Phosphate	Orthophosphate	Ammonia (N)	Hardness	Alkalinity pH 4.5	Iron	Manganese	
			Unit	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	%		oC	uS/cm	O2	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	ug/l	ug/l	
88022443	Piezo PTB2	GW -peat	EA DET numl241	237	207	211	9584	1072	183	7044	61	67	77	9901	9824	116	117	118	192	180	111	158	162	6051	6050	
88022302	Borehole D	GW S&G	10/03/2016	2	0.76	8.72	2.54	29.3	24.9	<10	-39.7	4.85	7.8	135.5	31.7	3.77	<2	0.13	0.07	0.14	0.1	7.62	8.11	24	626	39.8
88022302	Borehole D	GW S&G	26/07/2016	90.4	28.7	37.6	3.99	193	91	112			11.3	896			23.7	10.9	<0.04		<0.3	344	158	157	429	
88022302	Borehole D	GW S&G	16/08/2016					179	84.9		-0.51	6.66	10.8	851	14.7	14	14	<0.004		<0.1	<0.3	318	147			
88022443	Piezo PTB2	GW -peat	10/03/2016	2	0.76	8.72	2.54	29.3	24.9	<10	-39.7	4.85	7.8	135.5	31.7	3.77	<2	0.13	0.07	0.14	0.1	7.62	8.11	24	626	39.8
88022443	Piezo PTB2	GW -peat	16/08/2016	1.65	0.67	8.79	3.21	35.4	26.4	<10	-44	4.71	12.8	560.7	51.6	5.45	<0.2	0.12	0.08	0.24	0.15	0.1	6.87	29	709	30.8
88022445	Piezo PTC	GW -below peat	10/03/2016	75.1	29	22.9	6.58	325	73.8	37.6	-5.8	6.92	8.7	695.2	0.1	0.01	<2	<0.196	<0.004	0.12	0.11	0.87	307	266	<30	408
88022445	Piezo PTC	GW -below peat	16/08/2016	72.4	27.4	22.8	6.69	317	63.6	46.3	-6.27	6.82	9.2	89.3	13.4	1.54	0.24	0	0.09	0.1	0.85	294	260	30	373	
88022451	Borehole SGA3	GW S&G	10/03/2016	95.1	12.7	57.9	5.66	140	124	64.3	0.38	6.49	10.6	877	17.5	1.94	17.6	<0.004	<0.02	<0.1	<0.03	290	115	98.5	<10	
88022451	Borehole SGA3	GW S&G	16/08/2016	86.1	12.9	49.3	4.24	143	98.8	56.6	0.15	7.17	10.7	851	19.6	2.17	18	<0.004	0.02	<0.1	0.03	268	117	48.8	10	
88023757	Outflow at weir	Surface Water	06/11/2015	45.7	20.6	18	9.23	242	40.9	17.5	-4.74	7.29	11.4	447	15.3	1.67	<2	<0.196	<0.004	0.46	0.42	0.15	199	198	1130	374
88023757	Outflow at weir	Surface Water	10/03/2016	37.8	16.6	14.5	6.89	174	30.4	22.3	-1.65	7.07	5.7	393.1	43.2	5.41	<2	<0.196	<0.004	0.12	0.11	0.25	163	143	434	157
88023757	Outflow at weir	Surface Water	16/08/2016	47.4	19.4	15.3	6.25	211	31.1	26.9	-1.27	7.36	14.9	432.9	6.5	0.66	<0.2	<0.196	<0.004	0.27	0.24	0.03	198	173	269	355
88023758	Pool 1	Surface Water	06/11/2015	46.4	19	16	5.05	222	36.5	32.5	-6.51	6.87	10.7	469	18.4	2.04	<2	<0.196	<0.004	0.15	0.07	0.24	194	182	81.1	226
88023758	Pool 1	Surface Water	10/03/2016	36.1	15.2	13.4	4.47	154	28.7	26.5	-1.9	6.69	8.2	453.7	4.1	0.48	<2	<0.196	<0.004	0.17	0.03	0.28	153	126	281	189
88023758	Pool 1	Surface Water	16/08/2016	43.5	18.2	14.6	4.27	179	30.1	36.3	-1.62	6.6	10.5	197.1	6.4	0.71	<0.2	<0.196	0.01	0.05	0.03	0.11	184	147	97.7	219
88023759	Main Pool	Surface Water	06/11/2015	<1	0.77	4.73	0.69	14.6	12.9	<10	-42.1	4.1	11.8	81.9	34.6	3.74	<2	<0.196	<0.004	0.32	<0.1	0.04	5.67	12	755	44.9
88023759	Main pool	Surface Water	10/03/2016	<1	0.36	2.3	0.74	<6.1	6.8	<10	-44.3	3.97	5.9	50.1	33.5	4.17	<2	<0.196	<0.004	0.02	<0.1	<0.03	3.97	<5	407	12.9
88023759	Main Pool	Surface Water	16/08/2016	1.13	1.05	3.55	2.29	8.54	10.1	<10	-29	3.93	22.9	149.9	43.7	3.75	<0.2	<0.196	<0.004	0.29	<0.1	0.75	7.14	7	710	26.9
88023760	Lag Fen	Surface Water	06/11/2015	57.4	21.7	10.6	3.09	200	28.8	49.8	0.47	6.97	11.6	557.1	3.6	0.39	<2	<0.196	<0.004	0.12	0.01	0.06	233	164	2160	1360
88023760	Lag Fen	Surface Water	10/03/2016	85.7	30.9	12	4.28	207	26.4	120	5.65	6.94	6.6	498.3	10.3	1.26	<2	<0.196	<0.004	0.99	<0.1	<0.03	341	170	16900	1960
88023760	Lag Fen	Surface Water	16/08/2016	78.2	28	10.9	4.51	273	28.7	43.5	4.52	6.98	13.6	811	20.4	2.12	<0.2	<0.196	<0.004	0.18	<0.1	0.03	311	224	12800	12900
88023761	Precipitation	Precipitation	12/01/2016													0.2	0.19	0.01		0.36						
88023761	Precipitation	Precipitation	18/02/2016													0.2	0.19	0.01		0.46						
88023761	Precipitation	Precipitation	10/03/2016									6.03		70.8		0.14	0.14	0.01		0.42						
88023761	Precipitation	Precipitation	10/05/2016													0.61	0.59	0.02		0.98						
88023761	Precipitation	Precipitation	09/06/2016													0.34	0.33	0		0.05						
88023761	Precipitation	Precipitation	13/07/2016													0.23	0.23	0		0.19						
88023761	Precipitation	Precipitation	16/08/2016													0.24	0.24	0		0.11						
88023761	Precipitation	Precipitation	15/09/2016													0.41	0.4	0.01		0.27						
88023761	Precipitation	Precipitation	10/10/2016													0.08	0.08	0		0						
88023761	Precipitation	Precipitation	14/11/2016													0.24	0.22	0.01		0.39						
88023761	Precipitation	Precipitation	15/12/2016													0.18	0.17	0		0.08						

## Wybunbury Moss Inorganic Water Chemistry

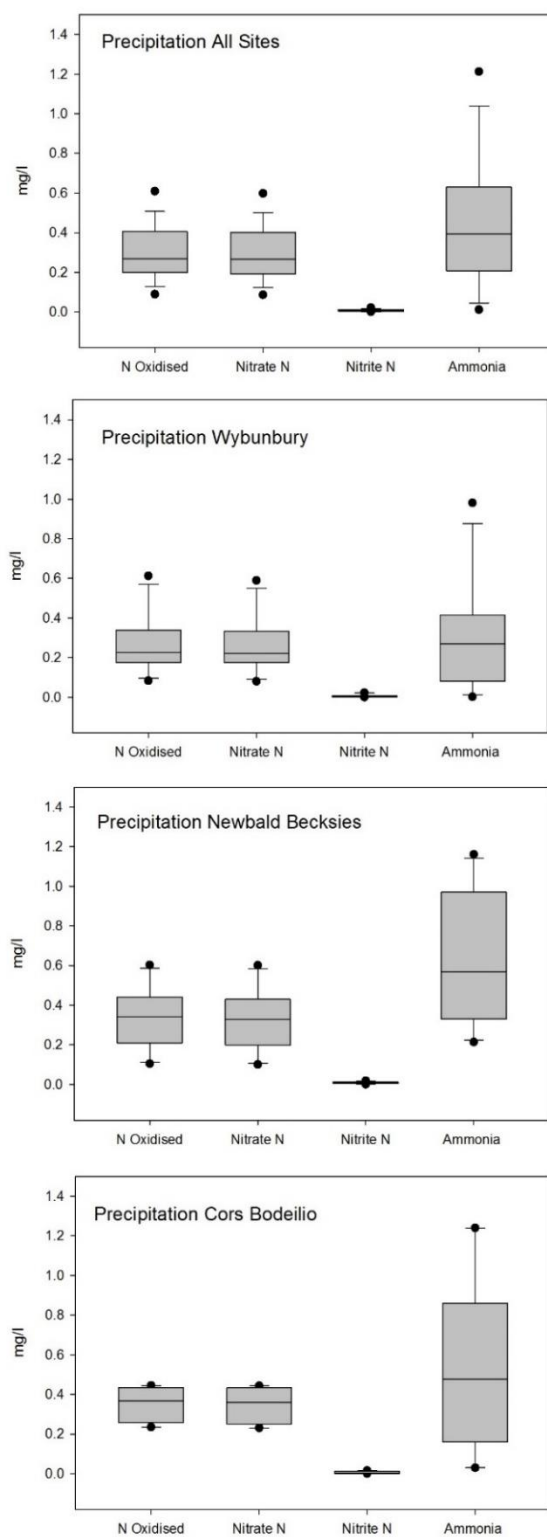


WIMS	Sample Point	Type	Date	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Chloride	Sulphate	Ionic Balance	pH	Temperature	Cond @ 25C	Oxygen Dissolved	Oxygen Dissolved	N Oxidised	Nitrate N	Nitrite N	Phosphate	Orthophosphate	Ammonia (N)	Hardness	Alkalinity pH <sub>4.5</sub>	Iron	Manganese
				Ca	Mg	Na	K	HCO3	Cl	SO4	%		oC	uS/c	O2	O2	N	N	N	P	OP	HN3	mg/l	Alk	Fe	Mn
			Unit	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l					%	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	ug/l	ug/l	ug/l
			EA DET number	241	237	207	211	9584	1072	183	7044	61	67	77	9901	9924	116	117	118	192	180	111	158	162	6051	6050
400G0097	Borehole Central	Groundwater	05/11/2015	107	2.2	15	0.7	163	43.3	50.1	-0.49	7.55	9.9	651	98.6	11.1	18.1	18	<0.004	0.0223	0.012	0.03	276	134	49.2	<10
400G0098	Borehole East	Groundwater	05/11/2015	101	2	11	0.7	170	36.9	38.7	0.202	7.56	9.8	591	98.7	11.2	14.9	15	<0.004	<0.02	<0.01	0.03	260	139	43.7	<10
400G0099	Borehole West	Groundwater	05/11/2015	116	2.4	16	0.7	162	44.2	56.8	2.03	7.51	10	674	93.1	10.5	19.1	19	<0.004	<0.02	<0.01	<0.03	300	133	254	10.7
400G0100	Springs 1	Groundwater	05/11/2015	98.4	1.8	11	0.6	170	33.4	34.7	1.44	7.68	9.8	570	94.2	10.7	13.1	13	<0.004	<0.02	<0.01	<0.03	253	139	<30	<10
400G0114	Spring West	Groundwater	05/11/2015	113	2.3	16	0.7	163	44.7	54.4	1.34	7.52	9.9	664	94.2	10.6	18.2	18	<0.004	<0.02	<0.01	<0.03	292	134	79.4	<10
49105159	Pipe	Groundwater	05/11/2015	106	2	12	0.6	176	37.3	42.4	0.631	7.53	9.8	618	92.5	10.5	15.5	16	<0.004	<0.02	<0.01	0.03	273	144	<30	<10
400G0097	Borehole Central	Groundwater	08/03/2016	117	2.5	17	0.7	159	43.6	56.6	4	7.54	9.2	655	91	10.4	18	18	<0.004	<0.02	0.011	0.03	302	130	<30	<10
400G0098	Borehole East	Groundwater	08/03/2016	111	2.2	13	0.6	160	39	46.8	3.54	7.54	9.5	591	91.7	10.5	16.5	17	<0.004	<0.02	<0.01	0.03	286	131	<30	<10
400G0099	Borehole West	Groundwater	08/03/2016	120	2.6	16	0.8	167	43.7	59	3.18	7.55	8.7	669	98.9	11.5	18.2	18	<0.004	<0.02	0.011	0.03	310	137	91.8	<10
400G0100	Springs 1	Groundwater	08/03/2016	106	1.9	12	0.5	173	35.2	37.1	3.1	7.55	9.4	565	97.6	11.2	14	14	<0.004	<0.02	<0.01	0.03	272	142	<30	<10
400G0114	Spring West	Groundwater	08/03/2016	117	2.5	17	0.7	161	43.5	58.6	3	7.52	8.6	668	84.9	9.89	18.3	18	<0.004	<0.02	<0.01	0.03	302	132	<30	<10
49105159	Pipe	Groundwater	08/03/2016	111	2.3	15	0.6	162	39	49.5	3.18	7.6	9.1	621	76.5	8.8	16.7	17	<0.004	<0.02	<0.01	0.03	286	133	<30	<10
400G0097	Borehole Central	Groundwater	18/08/2016	110	2.2	15	0.6	167	43.8	53.1	-0.53	7.4	9.8	650	96.1	10.9	18.3	18	<0.004	<0.02		<0.03	284	137	38.9	<10
400G0098	Borehole East	Groundwater	18/08/2016	103	1.9	11	0.6	172	36.6	43.5	-1.08	7.41	9.6	608	96.6	11	16.2	16	<0.004	<0.02		<0.03	265	141	<30	<10
400G0099	Borehole West	Groundwater	18/08/2016	114	2.4	16	0.7	168	46.4	57.9	0.013	7.38	10	681	97.7	11	18.6	19	<0.004	<0.02		<0.03	294	138	47.8	<10
400G0100	Springs 1	Groundwater	18/08/2016	105	2	11	0.7	177	36.3	38.6	1.07	7.44	9.7	578	94	10.7	14.7	15	<0.004	<0.02		<0.03	270	145	62.3	<10
400G0114	Spring West	Groundwater	18/08/2016	113	2.3	15	0.6	166	44.6	55	0.533	7.39	10	673	90.9	10.1	18.4	18	<0.004	<0.02		<0.03	292	136	<30	<10
49105159	Pipe	Groundwater	18/08/2016	106	2	12	0.5	176	38.9	45.4	-0.89	7.44	10	638	92.5	10.3	16.7	17	<0.004	<0.02		<0.03	273	144	<30	<10
400G0113	Rain Guage	Precipitation	08/12/2015														0.22	0.2	0.012			0.648				
400G0113	Rain Guage	Precipitation	15/01/2016														0.269	0.3	0.004			0.336				
400G0113	Rain Guage	Precipitation	01/03/2016														0.355	0.3	0.006			0.514				
400G0113	Rain Guage	Precipitation	03/05/2016														0.444	0.4	0.012			0.964				
400G0113	Rain Guage	Precipitation	07/06/2016														0.326	0.3	0.019			0.987				
400G0113	Rain Guage	Precipitation	01/07/2016														0.602	0.6	<0.001			0.312				
400G0113	Rain Guage	Precipitation	01/08/2016														0.105	0.1	0.004			0.624				
400G0113	Rain Guage	Precipitation	15/09/2016														0.391	0.4	0.015			1.16				
400G0113	Rain Guage	Precipitation	17/10/2016														0.441	0.4	0.012			0.396				
400G0113	Rain Guage	Precipitation	24/11/2016														0.177	0.2	0.005			0.214				

## Newbald Becksies Inorganic Water Chemistry

WIMS	Sample Point	Type	Date	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Chloride	Sulphate	Ionic Balance	pH	Temperature	Cond @ 25C	Oxygen Dissolved	Nitrate N	Nitrite N	Phosphate	Orthophosphate	Ammonia (N)	Hardness	Alkalinity pH 4.5	Iron	Manganese	
			Unit	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	%		oC	us/c	O2	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	ug/l	ug/l	ug/l	
			DET number	241	237	207	211	9584	1072	183	7044	61	67	77	9901	9924	116	117	118	192	180	111	158	162	6051 6050
28108	Bodellio Farm Pond	Groundwater	02/03/2015	136	3.95	11.7	4.14	377	29.1	16.1	0.75		8	712	92.8	10.97	3.86	3.86	<0.004	0.03	<0.02	<0.03	356	309	
28108	Bodellio Farm Pond	Groundwater	24/02/2016	130	3.52	13	3.93	333	29.8	15.3	2.79		8.4	681	101	11.79	5.88	5.88	<0.004		<0.02	<0.03	339	273	
28108	Bodellio Farm Pond	Groundwater	07/03/2016	130	3.48	12.5	3.74	388	29	15.7	-3.2		8.3	681	89.3	10.48	5.62	5.62	<0.004	<0.02	<0.02	<0.03	339	318	
28108	Bodellio Farm Pond	Groundwater	26/09/2016	136	4.3	12.8	4.65	401	21.9	15.2	0	7.36	14.2	714	103	10.55	0.3	0	0.005	<0.02	<0.02	<0.03	0	329	
28108	Bodellio Farm Pond	Groundwater	17/10/2016	145	4.51	12.7	5.02	436	21.2	16	0		11.9	737	68.6	7.39	0.89	0	0.013	0.03	<0.02	0.031	0	357	
28113	Fly Orchid Spring	Groundwater	02/03/2015	142	3.79	11.3	2.59	356	28.1	14.4	0.92		10.4	748	58.5	6.53	12.3	12.3	<0.004	0.02	<0.02	<0.03	370	292	
28113	Fly Orchid Spring	Groundwater	07/03/2016	138	3.52	11.7	2.36	356	23	13	4.43		10.1	704	39.2	4.40	4.6	4.6	<0.004	<0.02	<0.02	<0.03	359	292	
28113	Fly Orchid Spring	Groundwater	26/09/2016	178	4.23	13.8	2.75	449	22.9	17.2	0	7.08	12.8	812	46.4	4.90	2.63	0	<0.004		<0.02	<0.03	0	368	
28113	Fly Orchid Spring	Groundwater	17/10/2016	161	4.18	13	2.72	472	21.7	15.9	0		10.7	812	28.7	3.18	2.71	0	<0.004	0.03	<0.02	<0.03	0	387	
28174	Pentraeth Verge Borehole	Groundwater	05/05/2016	66.9	42.7	50.2	1.77	409	31.7	36.3	N0		9.8	388	79.2	8.96	4.83	4.83	<0.004		<0.02	<0.03	335		
28249	Piezo BD2A (1.15m)	Groundwater	12/10/2015	132	16.8	13.1	0.66	459	19.3	43.9	-2.7		12.9	626	46.9	4.94	0.66	0.656	<0.004	0.04	<0.02	0.085	399	376	
28249	Piezo BD2A (1.15m)	Groundwater	07/03/2016	132	12.1	12.4	0.48	500	16.3	10.7	-4.6		6.2	625	29.2	3.61	0.48	0.476	<0.004	<0.02	<0.02	<0.03	379	410	
28249	Piezo BD2A (1.15m)	Groundwater	17/10/2016	163	13.8	11.1	0.46	536	15.5	<10	0		12.4	834	32.8	3.49	<0.2	0	<0.004	0.05	<0.02	0.03	0	439	
28250	Borehole BD1 (5.3m)	Groundwater	05/03/2015	139	6.38	7.75	0.99	381	15.2	16	4.1	6.93	10.7	625	30.2	3.35	3.35	2.89	<0.04		<0.2	<0.3	373	312	
28250	Borehole BD1 (5.3m)	Groundwater	12/10/2015	145	6.95	9.67	1.1	448	21.8	22.4	3.21	6.9	11.3	733	15.2	1.66	1.66	5.36	<0.04		<0.2	<0.3	391	367	
28250	Borehole BD1 (5.3m)	Groundwater	07/03/2016	130	5.7	7.43	0.95	407	15.6	14.7	-2.4		10.4	667	32.4	3.62	3.24	3.24	<0.004	<0.02	<0.02	<0.03	348	334	
28250	Borehole BD1 (5.3m)	Groundwater	17/10/2016	141	6.38	7.55	0.94	412	12.6	16.9	0		11.4	689	16	1.74	1.9	0	<0.004	0.02	<0.02	<0.03	0	338	
28251	Borehole BD1 (5.3m)	Groundwater	05/03/2015	150	7.5	12.3	0.86	401	16.5	16	4.6		10.4	704	33.4	3.73	7.27	7.27	<0.004	0.1	<0.02	<0.03	405	329	
28251	Borehole BD1 (5.3m)	Groundwater	12/10/2015	154	7.95	16.8	1.07	299	20.6	18.9	18.6	6.85	11.4	789	12.8	1.40	1.4	5.1	<0.04		<0.2	<0.3	417	245	
28251	Borehole BD1 (5.3m)	Groundwater	12/10/2015	154	7.95	16.8	1.07	299	20.6	18.9	18.6		11.4	789	12.8	1.40	5.1	5.1	<0.004	0.02	<0.02	<0.03	417	245	
28251	Borehole BD1 (5.3m)	Groundwater	07/03/2016	159	7.36	11.1	0.78	494	16.9	16	-0.3		10.1	809	26	2.92	2.6	2.6	<0.004	<0.02	<0.02	<0.03	427	405	
28251	Borehole BD1 (5.3m)	Groundwater	17/10/2016	169	8.27	12.3	0.94	500	15	18	0		11.7	824	12.8	1.39	1.73	0	<0.004	0.04	<0.02	<0.03	0	410	
28383	Borehole BD3 Stone Sci. (18m)	Groundwater	16/10/2015	92.8	13.7	15.4	2.04	333	22.8	16.5	0.15	7.16	10.8	347	6.5	0.72	0.72	<196	<0.04		<0.2	0.035	288	273	
28384	Borehole BD4 Stone Sci. (8m)	Groundwater	16/10/2015	181	11.3	20.8	2.78	726	41.8	15.6	10.4	6.97	11.2	417	7.9	0.87	0.87	1.04	<0.04		0.026	<0.3	498	595	
40000506	Precipitation	Precipitation	01/08/2016														0.24	0.231	0.005					0.478	
40000506	Precipitation	Precipitation	30/08/2016														0.33	0.314	0.015					1.24	
40000506	Precipitation	Precipitation	29/09/2016																					<0.03	
40000506	Precipitation	Precipitation	26/10/2016														0.41	0.404	<0.001					0.289	
40000506	Precipitation	Precipitation	29/11/2016														0.45	0.443	0.002					0.481	

## Cors Bodeillio Inorganic Water Chemistry



**Precipitation (wet) rainfall chemistry 2015-2016**

## NITROGEN AND OXYGEN ISOTOPES

Site	Sample Point	Date	d <sup>15</sup> N-	d <sup>18</sup> O-	Nitrate-N (mg/L)	Nitrite- N (ug/L)	Ammonia- N (ug/L)	Phosphate- P (ug/L)	Silicate- Si (ug/L)
			NO <sub>3</sub> ‰	NO <sub>3</sub> ‰					
Wybunbury Moss	Piezomter 'PTC'	10/03/2016	6.1	7.6	0.0	0.0	480.7	6.87	1911
Wybunbury Moss	Dipwell B2	10/03/2016	11.7	2.4	1.7	10.8	209.2	16.8	167
Wybunbury Moss	Borehole SGA3	10/03/2016	11.8	1.5	20.2	0.3	20.4	0.0	456
Wybunbury Moss	Pool 'M1'	10/03/2016	concentration to		0.0	0.3	321.5	22.39	2449
Wybunbury Moss	Pool 'Main'	10/03/2016	11.6	5.7	0.0	3.6	212.6	0.52	49
Wybunbury Moss	Lag Fen	10/03/2016	6.7	16.7	0.0	0.3	23.1	0.0	2445
Wybunbury Moss	Outflow at Weir	10/03/2016	6.3	1.8	0.2	0.4	92.6	8.93	645
Wybunbury Moss	Borehole SGA3	05/11/2015	11.4	1.7	18.9	0.0	20.8	0.0	524
Wybunbury Moss	Pool 'M1'	05/11/2015	6.3	24.8	0.0	3.7	57.1	1.05	1337
Wybunbury Moss	Pool 'Main'	05/11/2015	concentration to		0.0	1.2	16.9	0.0	21
Wybunbury Moss	Lag Fen	05/11/2015	concentration to		0.0	3.8	225.6	1.51	2408
Wybunbury Moss	Outflow at Weir	05/11/2015	concentration to		0.0	1.1	6.2	61.07	2406
Wybunbury Moss	Dipwell B2	16/08/2016	concentration to		0.1	26.8	1925.2	13.6	75
Wybunbury Moss	Pool 'M1'	16/08/2016	concentration to		0.0	2.5	11.9	1.7	1451
Wybunbury Moss	Borehole 'D '	16/08/2016	9.99	0.84	4.8	1.4	1.2	0.5	598
Wybunbury Moss	Lag Fen	16/08/2016	6.09	2.86	0.5	1.0	18.5	0.9	840
Wybunbury Moss	Pool 'Main'	16/08/2016	8.30	5.82	0.0	1.9	12.6	1.1	38
Wybunbury Moss	Outflow at Weir	16/08/2016	7.51	0.58	0.3	9.0	299.3	91.5	2180
Wybunbury Moss	Piezomter 'PTC'	16/08/2016	9.20	4.33	0.2	1.1	333.7	92.3	1054
Wybunbury Moss	Borehole SGA3	16/08/2016	9.95	0.20	5.1	1.0	2.9	0.5	521
Newbald Becksies	Borehole West	08/03/2016	4.9	0.3	19.6	2.9	17.5	0.0	2054
Newbald Becksies	Borehole East	08/03/2016	4.8	0.7	13.0	0.0	9.5	0.0	1416
Newbald Becksies	Borehole West	04/11/2015	4.8	0.4	20.2	0.0	10.1	0.0	861
Newbald Becksies	Borehole East	04/11/2015	4.7	0.7	16.0	0.4	13.1	0.0	693
Newbald Becksies	Borehole Central	04/11/2015	3.0	0.4	25.2	0.9	9.2	0.0	428
Newbald Becksies	Spring 1	04/11/2015	4.7	0.9	15.1	0.0	20.7	0.0	438
Newbald Becksies	Pipe Outflow	04/11/2015	4.4	0.5	9.2	0.0	12.5	0.0	847
Newbald Becksies	Spring West	04/11/2015	5.4	1.3	17.0	0.0	9.2	0.0	900
Newbald Becksies	Borehole Central	08/03/2016	4.8	0.3	17.9	0.0	9.4	0.0	871
Newbald Becksies	Outflow	04/11/2015	5.0	1.5	14.0	0.3	26.2	0.0	585
Newbald Becksies	Spring 1	08/03/2016	4.5	0.3	16.8	0.0	8.4	0.0	726
Newbald Becksies	Pipie Outflow	08/03/2016	5.2	2.0	23.5	0.0	25.9	0.0	736
Newbald Becksies	Borehole East	18/08/2016	3.82	-0.14	14.1	0.4	9.4	0.3	647
Newbald Becksies	Borehole Central	18/08/2016	4.03	0.14	15.4	1.1	2.7	0.4	761
Newbald Becksies	Borehole West	18/08/2016	4.00	-0.01	17.9	1.1	4.9	0.4	793
Newbald Becksies	Outflow	18/08/2016	4.45	0.65	7.4	3.9	1.8	0.4	838
Newbald Becksies	Spring West	18/08/2016	4.07	-0.19	17.1	1.4	0.5	0.5	577
Newbald Becksies	Pipe Outflow	18/08/2016	4.11	0.68	15.6	1.0	2.8	0.5	2177
Newbald Becksies	Spring West	08/03/2016	5.1	1.0	21.2	0.0	8.1	0.0	752
Newbald Becksies	Spring 1	18/08/2016	3.59	-0.35	11.7	0.0	5.7	0.4	675
Cors Bodeilio	Piezomter BD2A	09/03/2016	8.5	3.6	2.6	0.0	16.9	0.0	726
Cors Bodeilio	Main Drain	09/03/2016	10.1	5.5	0.5	0.0	13.7	0.0	205
Cors Bodeilio	Car Park Drain	09/03/2016	8.6	3.8	4.9	0.0	11.5	0.0	445
Cors Bodeilio	Bodeilio Farm Pond	16/02/2016	10.3	4.5	1.7	0.0	35.5	0.0	524
Cors Bodeilio	Fly Orchid Spring	16/02/2016	9.2	4.2	2.1	0.0	15.9	0.0	425
Cors Bodeilio	Treatment wetland	16/02/2016	10.2	5.9	1.9	7.1	36.3	0.0	1007
Cors Bodeilio	Piezomter BD2A	16/02/2016	8.4	3.8	0.9	0.0	13.4	0.0	763
Cors Bodeilio	Main Drain	16/02/2016	10.3	4.6	0.9	1.8	44.7	0.0	820
Cors Bodeilio	Car Park Drain	16/02/2016	8.1	3.5	5.8	0.0	8.5	0.0	529
Cors Bodeilio	Dipwell 16	16/02/2016	7.9	31.8	0.1	1.7	216.9	0.0	1158
Cors Bodeilio	Bodeilio Farm Pond	17/08/2016	concentration to		0.0	0.3	0.0	13.1	698
Cors Bodeilio	Piezomter BD2A	17/08/2016	8.89	4.47	0.6	1.2	0.1	0.4	479
Cors Bodeilio	Dipwell 16	17/08/2016	15.27	8.90	0.6	3.3	109.7	1.0	993
Cors Bodeilio	Treatment wetland	17/08/2016	6.81	6.35	0.0	0.0	28.1	0.7	1146
Cors Bodeilio	Fly Orchid Spring	17/08/2016	14.09	7.58	0.3	1.5	38.0	0.9	525
Cors Bodeilio	Main Drain	17/08/2016	5.52	4.76	0.0	0.6	3.7	0.5	940
Cors Bodeilio	missing sample tube		missing sample t		0.0	20.4	1920.9	57.5	84.8
Cors Bodeilio	Bodeilio Farm Pond	09/03/2016	10.6	4.0	1.3	0.0	15.5	0.0	392
Cors Bodeilio	Fly Orchid Spring	09/03/2016	9.3	3.1	2.3	0.0	14.1	0.0	575
Cors Bodeilio	Treatment wetland	09/03/2016	9.9	5.9	1.2	0.3	2.8	0.0	455

## SAMPLE POINTS AND PHOTOGRAPHS

Easting, Northing and Elevation

Site	Name	Easting	Northing	Elevation E & N		Elevation
				maOD	quality (m)	quality (m)
Newbald_Becksies	Spring_1	491900	437109	46.96	0.01	0.02
Newbald_Becksies	Spring_2	491928	437127	47.10	0.01	0.02
Newbald_Becksies	Spring_C	491858	437109	46.74	0.01	0.01
Newbald_Becksies	Spring_D	491820	437098	46.93	0.01	0.01
Newbald_Becksies	Spring_2	491718	437086	44.75	0.01	0.02
Newbald_Becksies	SP2 MAIN D	491714	437113	44.31	0.01	0.01
Newbald_Becksies	Outflow	491662	437098	43.71	0.01	0.01
Newbald_Becksies	Star_flow	491599	437069	44.39	0.19	0.40
Newbald_Becksies	Borehole_West	491720	437059	48.44	0.01	0.01
Newbald_Becksies	Borehole_Central	491789	437075	49.08	0.01	0.02
Newbald_Becksies	Boreholes_East	491882	437097	49.31	0.01	0.02
Newbald_Becksies	Diffusion_Tubes	491877	437123	48.52	0.01	0.01
Wybunbury_Moss	Diffusion_Tubes	369649	350240	50.14	0.01	0.01
Wybunbury_Moss	Borehole_SGA3	369594	350383	51.99	0.01	0.02
Wybunbury_Moss	Borehole_D	369589	350384	51.87	0.01	0.02
Wybunbury_Moss	Borehole_C	369591	350387	51.83	0.01	0.01
Wybunbury_Moss	Piezo_PTB2	369637	350260	48.79	0.01	0.02
Wybunbury_Moss	Piezo_PTB	369638	350261	48.22	0.01	0.01
Wybunbury_Moss	Main_Pool	369574	350213	48.25	0.01	0.01
Wybunbury_Moss	Pool_M1	369734	350128	48.23	0.01	0.01
Wybunbury_Moss	Outflow_Wier	369972	350107	48.11	0.33	0.52
Wybunbury_Moss	South_Lag	369869	350101	48.22	0.01	0.02
Wybunbury_Moss	Lag_Fen	369606	350367	48.60	0.01	0.01
Cors_Bodeilio	Main_drain	250227	377584	29.21	0.01	0.01
Cors_Bodeilio	Fly_Orchid_Spring	250020	377720	30.77	0.01	0.01
Cors_Bodeilio	Dipwell_16	250531	377189	30.75	0.01	0.00
Cors_Bodeilio	Piezo_BD2a	250346	377539	29.68	0.01	0.01
Cors_Bodeilio	Bodeilo_Farm_Spring	249722	377703	poor reception & accuracy		
Cors_Bodeilio	Field_Drain	250645	377316	poor reception & accuracy		
Cors_Bodeilio	Treatment_Wetland	250631	377434	poor reception & accuracy		
Cors_Bodeilio	Diffusion_Tubes	250531	377342	poor reception & accuracy		

## Wybunbury Moss Sample Points



Dipwell B2, B3 and B1 (left to right) (peat)



SGA3 (sand and gravel borehole)



Piezometer PTC (below peat raft)



'Main' Pool on bog surface



Pool 1 (south side of site)



Lag Fen (sample of standing water)



Outflow at weir



Diffusion tubes (next to PTC piezometer)



## Newbald Becksies Sample Points



Borehole West



Spring 1



Borehole Central



Spring 2



Borehole East



Pipe (disused)



Outflow with star gauge monitoring flow



Diffusion tubes (next nest of peizos)



## Cors Bodeilio Sample Points



Piezometer BD2a (artesian)



Treatment wetland for high N water



Bodeilio Farm Spring Pond



Fly Orchid Spring (dry summer 2016)



Dipwell BD16



Pipe nr carpark into wetland



Main axial drain (summer time)



Diffusion tube, rain gauge.

